THE BRIDGEWATER TREATISES

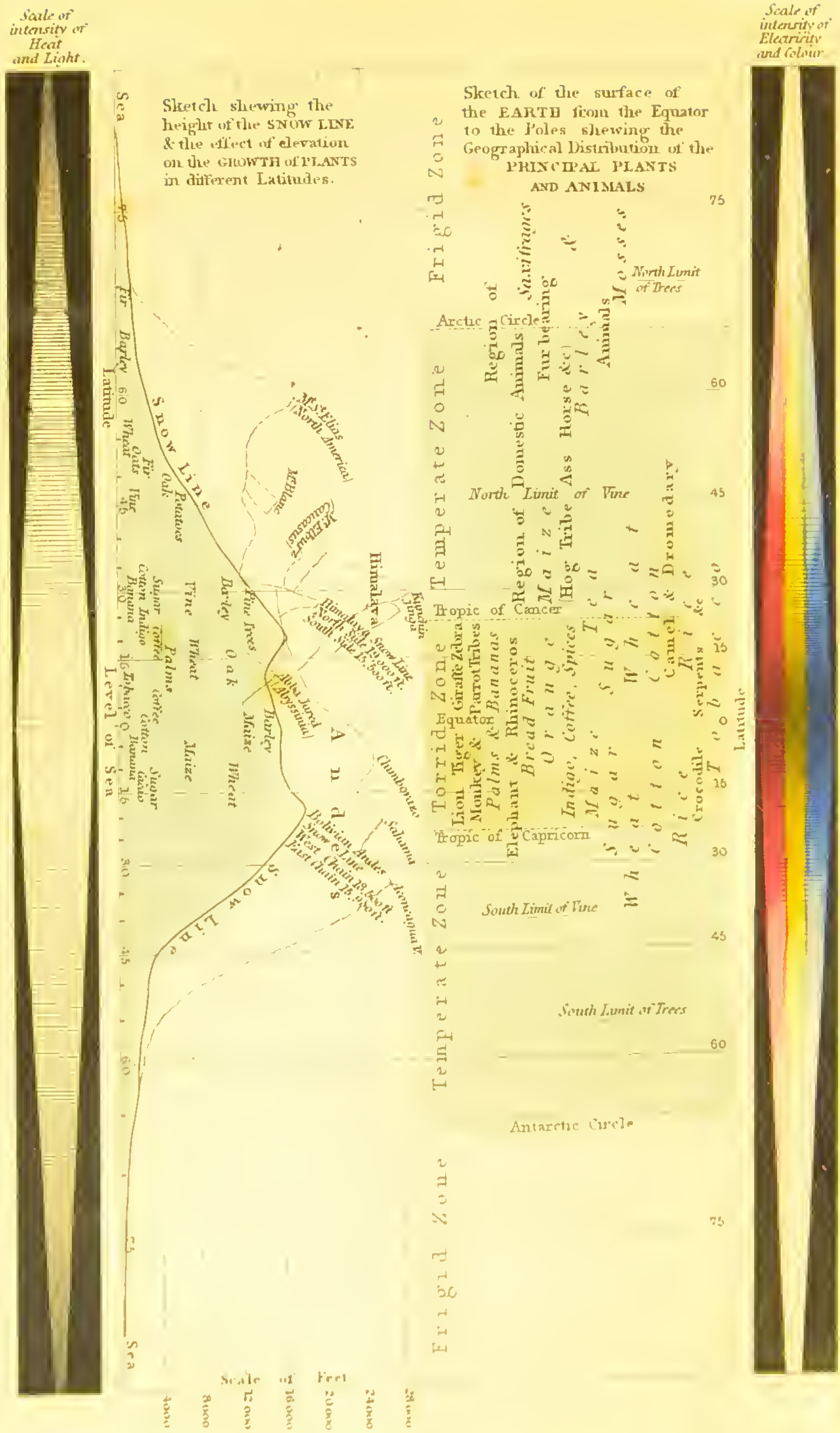
ON THE POWER, WISDOM, AND GOODNESS,
OF GOD,
AS MANIFESTED IN THE CREATION.

CHEMISTRY, METEOROLOGY, AND THE FUNCTION
OF DIGESTION,

BY WILLIAM PROUT, M.D., F.R.S.

Μὴ ὑπαρχούσας γάρ ἁρμονίας καὶ ’ΕΠΟ΄ΨΙΟΣ ΘΕΙΑΣ *περὶ τὸν κόσμον, οὐκ ἂν ἐδύνατο συνεῖμεν ἔτι καλῶς ἔχοντα τὰ ἐγκεκοσμαμένα.*

HIPPODAMUS DE FELICITATE.


Scale of intensity of Heat and Light.
Scale of intensity of Electricity and Colour
Sketch shewing the height of the SNOW LINE & the effect of elevation on the GROWTH of PLANTS in different Latitudes.
Sketch of the surface of the EARTH from the Equator to the Poles shewing the Geographical Distribution of the PRINCIPAL PLANTS AND ANIMALS
Sea
Snow Line
Latitude
Level of Sea
Scale of Feet
4000
8000
12000
16000
20000
24000
28000
Fir
Barley
Wheat
Oats
Oak
Potatoes
Vine
Barley
Pine trees
Oak
Maize
Wheat
Sugar
Cotton
Indigo
Banana
Palms
Coffee
Mt St Elias (North America)
Mt Blanc
Mt Elburz (Caucasus)
Himalaya
Himalaya Snow Line
North Side 19,500 ft.
South Side 15,500 ft.
Andes
Chimborazo
Bolivian Andes Snow Line
West Chain 18,600 ft.
East Chain 15,900 ft.
Aconcagua
Frigid Zone
Temperate Zone
Torrid Zone
Temperate Zone
Frigid Zone
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
North Limit of Trees
North Limit of Vine
South Limit of Vine
South Limit of Trees
Region of Saxifrages
Mosses
Region of Fur bearing Animals
Region of Domestic Animals
Horse &c.
Ass
Hog Tribe
Barley
Maize
Wheat
Tea
Sugar
Cotton
Camel & Dromedary
Rice
Tobacco
Lion Tiger Giraffe Zebra
Monkey & Parrot Tribes
Palms & Bananas
Elephant & Rhinoceros
Bread Fruit
Orange
Indigo, Coffee, Spices
Crocodile
Serpents
Latitude
75
60
45
30
15
0
15
30
45
60
75

CHEMISTRY, METEOROLOGY,

AND THE FUNCTION OF DIGESTION,

CONSIDERED WITH REFERENCE TO

NATURAL THEOLOGY.

BY WILLIAM PROUT, M.D., F.R.S.

FELLOW OF THE ROYAL COLLEGE OF PHYSICIANS.

FOURTH EDITION.

EDITED

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LONDON:

HENRY G. BOHN, YORK STREET, COVENT GARDEN.

1855.

16748

PRINTED BY HARRISON AND SONS,
LONDON GAZETTE OFFICE, ST. MARTIN'S LANE.

TO

DAVIES GILBERT, ESQ.

LATE PRESIDENT OF THE ROYAL SOCIETY,

This Volume

IS

RESPECTFULLY INSCRIBED.

EDITOR'S PREFACE

TO THE PRESENT EDITION.

In editing this edition of the late Dr. Prout's *Bridgewater Treatise*, care has been taken to leave the author's text unaltered. The additions which have been made refer mainly to such matters of fact as recent investigations have brought to light, or have established upon a surer basis than heretofore.

In a few instances, relating to certain departments of science where novel and important views have been founded and adopted since the publication of the last edition, reference has been made to some work in which full information may be obtained. The addition of these would have required the introduction of details inconsistent with the character and objects of the work.

G.

St. John's Square, *May*, 1855.

AUTHOR'S PREFACE.

[FIRST EDITION.]

Chemistry has not hitherto been considered in detail with reference to Natural Theology; the difficulties, therefore, incidental to a first attempt, added to those arising from the nature of Chemistry itself as a science, must be the apology of the author for numerous imperfections in this treatise.

The peculiar chemical opinions advanced, would never have appeared in their present form, had not the author been strongly impressed with the belief that they are calculated, sooner or later, to bring chemical action under the dominion of the laws of quantity; and had he not despaired, under his professional engagements, of being himself able to submit them to experimental proof. These opinions, however, have been always introduced as mere illustrations.

The argument of design is necessarily cumulative; that is to say, is made up of many similar arguments. To avoid repetitions, therefore, the illustration of principles rather than of details, has been studied; and the application of particular facts to the argument, has been often left to the Reader.

London, *February* 3, 1834.

TO THE READER.

[SECOND EDITION.]

The Author, in certain parts of this treatise, having been misunderstood, is anxious to state more prominently than in the first edition, *that no argument illustrative of design has been founded on the supposed molecular arrangements which he has given;* and that the reality of design in the phenomena of chemistry is no more affected by the truth or falsehood of his theory, than the moral of a fable is affected by the truth or falsehood of its imaginary incidents.

The phenomena of chemistry can neither be represented by figures, nor adequately described to the inexperienced by words. The consideration of chemistry, therefore, with reference to the argument of design, presents peculiar difficulties. After much reflection, the author has omitted details which every treatise on the subject will furnish, and has endeavoured to convey some notion of the wonders of molecular action. As the best suited to his purpose, a sketch of his own views is given: and if the uninformed reader learn from this sketch, that the *invisible* operations of chemistry are at least as wonderful as the *visible* operations of mechanism, the author will attain one of his objects. He will attain another object, if what has been stated, in any way contribute to the advancement of knowledge.

In this edition the introductory observations have been enlarged; a few errors have been rectified, and the arrangement of some parts altered: but with the exception of these changes, the work remains essentially the same as in the first edition.

LONDON, *June* 7, 1834.

TO THE READER.

[THIRD EDITION.]

A NEW edition of this Treatise having been called for, the Author, after so long an interval, considers the following statement to be neeessary:—

First. The views regarding Assimilation contained in former editions of this Treatise, as well as the Pathology of assimilation founded on these views, and published in the author's Inquiry into the nature and treatment of Stomach and Renal Diseases, have been very generally adopted by Physiologists. Professor Liebig and M. Dumas in particular now advocate views essentially the same; their slight difference not affecting the general principle originally proposed in the Bridgewater Treatise.

Seeondly. The moleeular arrangements before introduced into the text, have, in the present edition, been stated more briefly in the Appendix.

In this edition, though, by an enlargement of the page, much new matter has been added, there has been no increase of the size of the volume. The author is still conscious of many imperfeetions, arising in no small degree from his professional avocations. The varied and difficult nature of the points to be investigated, required more undivided attention than he has been able to bestow.

LONDON, *May* 1, 1845.

NOTICE.

The series of Treatises, of which the present is one, is published under the following circumstances:

The Right Honourable and Reverend Francis Henry, Earl of Bridgewater, died in the month of February, 1829; and by his last Will and Testament, bearing date the 24th of February, 1825, he directed certain Trustees therein named to invest in the public funds the sum of Eight thousand pounds sterling; this sum, with the accruing dividends thereon, to be held at the disposal of the President, for the time being, of the Royal Society of London, to be paid to the person or persons nominated by him. The Testator further directed, that the person or persons selected by the said President should be appointed to write, print, and publish one thousand copies of a work *On the Power, Wisdom, and Goodness of God, as manifested in the creation; illustrating such work by all reasonable arguments, as for instance the variety and formation of God's creatures in the animal, vegetable, and mineral kingdoms; the effect of digestion, and thereby of conversion; the construction of the hand of man, and an infinite variety of other arguments; as also by discoveries, ancient and modern, in arts, sciences, and the whole extent of literature.* He desired, moreover, that the profits arising from the sale of the works so published should be paid to the authors of the works.

The late President of the Royal Society, Davies Gilbert, Esq., requested the assistance of his Grace the Archbishop of Canterbury and of the Bishop of London, in determining upon the best mode of carrying into effect the intentions

of the Testator. Acting with their advice, and with the concurrence of a nobleman immediately connected with the deceased, Mr. Davies Gilbert appointed the following eight gentlemen to write separate Treatises on the different branches of the subject as here stated:

THE REV. THOMAS CHALMERS, D.D.

LATE PROFESSOR OF DIVINITY IN THE UNIVERSITY OF EDINBURGH.

ON THE POWER, WISDOM, AND GOODNESS OF GOD AS MANIFESTED IN THE ADAPTATION OF EXTERNAL NATURE TO THE MORAL AND INTELLECTUAL CONSTITUTION OF MAN.

JOHN KIDD, M.D., F.R.S.

REGIUS PROFESSOR OF MEDICINE IN THE UNIVERSITY OF OXFORD.

ON THE ADAPTATION OF EXTERNAL NATURE TO THE PHYSICAL CONDITION OF MAN.

THE REV. WILLIAM WHEWELL, D.D., F.R.S.

MASTER OF TRINITY COLLEGE, CAMBRIDGE.

ASTRONOMY AND GENERAL PHYSICS CONSIDERED WITH REFERENCE TO NATURAL THEOLOGY.

SIR CHARLES BELL, K.G.H., F.R.S. L. & E.

THE HAND: ITS MECHANISM AND VITAL ENDOWMENTS AS EVINCING DESIGN.

PETER MARK ROGET, M.D.

FELLOW OF AND SECRETARY TO THE ROYAL SOCIETY.

ON ANIMAL AND VEGETABLE PHYSIOLOGY.

THE REV. WILLIAM BUCKLAND, D.D., F.R.S.

CANON OF CHRIST CHURCH, AND PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF OXFORD.

ON GEOLOGY AND MINERALOGY.

THE REV. WILLIAM KIRBY, M.A., F.R.S.

ON THE HISTORY, HABITS, AND INSTINCTS OF ANIMALS.

WILLIAM PROUT, M.D., F.R.S.

CHEMISTRY, METEOROLOGY, AND THE FUNCTION OF DIGESTION, CONSIDERED WITH REFERENCE TO NATURAL THEOLOGY.

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BOOK I.

OF CHEMISTRY.

CH. I.—OF THE LEADING ARGUMENT OF NATURAL THEOLOGY; THAT DESIGN, OR THE ADAPTATION OF MEANS TO AN END, EXISTS IN NATURE.

A FULL exposition of the argument of design does not belong to this Treatise. In these introductory observations, we shall, therefore, confine ourselves to a statement of the argument, as deducible from a simple instance of the adaptation of means to an end, among the objects of nature: we shall then inquire into the validity of the argument of design; and shall show the conclusions to which that argument leads.

The instance of adaptation of means to an end which we select among the objects of nature; and the argument which may be deduced from that instance of adaptation, are the following:

Animals in cold climates have been provided with a covering of fur. Men in such climates cover themselves with that fur. In both cases, whatever may have been the end, or intention; no one can deny that the effect, at least, is precisely the same; the animal and the man are alike protected from the cold. Now, since the animal did not clothe itself, but must have been clothed by another; it follows, that whoever clothed the animal apparently knew

what the man knows, and reasoned like the man: that is to say, the clother of the animal knew that the climate in which the animal is placed is a cold climate; and that a covering of fur is one of the best means of warding off the cold; he therefore clothed his creature in this very appropriate material.

The man who clothes himself in fur to keep off the cold, performs an act directed to a certain end; in short, an act of design. So, whoever, directly or indirectly, caused the animal to be clothed with fur, to keep off the cold, must likewise have performed an act of design.

But, under the circumstances, the clother of the animal must be admitted to have been also the Creator of the animal; and, by extending the argument, the Creator of man himself—of the universe. Moreover, the intelligence the Creator has displayed in clothing the animal, He has deigned to impart to man; who is thus enabled to recognise his Creator's design.

Such is an instance of those varied adaptations of means to an end, which we behold in the world; and such the train of reasoning which, to common understandings, appears to show, that these adaptations are the effect of design. As there are, however, some men, whose minds are so obtuse, or so singularly constituted, that they maintain all these appearances of design to be unreal; a brief examination of the pretexts which they have urged for their incredulity, may not be deemed irrelevant.

The opposers of the argument of design may be divided into two classes;— those who, denying a First Cause, affect to believe, that all the beautiful adaptations and arrangements we witness in creation, arise from what they term, "the necessary and eternal laws of nature;" and who, in fact, are Atheists, or rather Pantheists, "to whom the laws of nature are as gods:"—and those who, without denying the existence of a First Cause, contend that the adaptations among the objects of nature cannot be proved to be the effect of design; that these objects appear to us well adapted to each other, because we have nothing, besides our own intellects, with which we can compare them; and that the limited powers of the human mind are a standard altogether inapplicable to the Deity.

The opposers of the argument of design, who assert the existence of "necessary and eternal laws of nature," need no other refutation, than the facts detailed throughout these Treatises. Those who allege that design cannot be proved, may be thus answered:

We have been gifted with mental faculties, by which we recognise certain abstract truths, or necessary existences; which abstract truths, or necessary existences, we cannot doubt, without doubting the existence of ourselves. We have been gifted with other faculties, by which we recognise the existence, and compare the properties, of things external to ourselves: but, so far as we can discover, neither the existence of these external things, nor the existence of their properties, is necessary; they might have existed quite otherwise than they are,—they even might never have had any existence. Now our knowledge of the manifestations of design, among the objects of nature, is derived entirely from those faculties, by which we recognise the existence, and compare the properties of objects external to ourselves. Hence nothing can be proved, either for or against what we term design in nature, by any argument founded on necessity; that is to say, by any *à priori* reasoning, founded on mere abstract truths, or necessary existences; and all such attempts must be not only unsatisfactory, but absurd.

At the commencement of this chapter, we have given a simple statement of the train of reasoning, on which we found our belief of the agency of an intelligent Creator.

An act, performed by ourselves, when directed to a certain end, we term an act of design. Among the objects of nature, we see the same end attained by the employment of the same means we ourselves employ. We are conscious of the will and the power which are requisite for the accomplishment of our own act; and are satisfied regarding the impossibility of that act, without our own, or similar agency. We thence infer, that without some external agency (implying a will and a power, similar to the will and the power exerted by ourselves), an act, similar to our own act, could not have been accomplished. Our belief then, in the agency of an intelligent Creator, is founded,—

On our recognition of the identity of effects produced in external nature, with effects produced by ourselves; from which identity of effect, we immediately infer identity of purpose,—the existence of design, without reference to a designer:

On our consciousness that the purpose effected by us proceeded from ourselves, the designers; whence we conclude, that the design manifested in external nature must have had a like origin,—that the manifestation of design is demonstrative of the existence of a designer:

On the pervading character of the design shown among the objects of nature; in which design, man recognises the creation of the objects designed; and is thus led to infer the existence of a Creator. Now the faculty of reason, which enables man to recognise the Creator of the objects around him, enables him to recognise in that Creator, the Creator of himself and of his faculties. In reasoning, therefore, from his own acts, to those of the Creator of the Universe, though conscious that he is reasoning from the finite to the Infinite; from weakness to Almighty power; —yet, when he reflects, from whom he has derived his faculty of reason, man feels assured that his own reasoning, when it coincides with the reasoning evinced by his Creator, can be no other than the same. Nor, founded, as that assurance is, on the constitution of the human mind, can such assurance be impugned; without impugning Him, by whom the human mind has been so constituted.

Thus the argument of design, though not based on necessity, in the strict sense of the term; is of a validity equal to that of our knowledge of the existence of, and of our connexion with, an external world. Speculative men may deny the existence of all things external to themselves; may even deny their own existence; but while they continue to act like other men, it is not easy to imagine them sincere. We at least, discard all such speculations, as worthless fallacies, and contend for the common-sense view of the existence and origin of things;—that design is design, whether exemplified in the works of man, or in the works of his Maker; a view which has been adopted by the wise and good in all ages; which has all the probabilities on its side; and which alone, of all others, points out to man his

true and natural position, among created beings. When man, indeed, compares himself with the universe, his own insignificance appears quite overwhelming; but the argument of design assures him that, insignificant as he is, while he investigates and approves of the order and harmony around him, he is exerting faculties truly god-like—that his reason, though limited in degree, is immortal in kind, and must thus differ from the reason of the great Architect of all things only in not being infinite. And hence the proud relationship in which man justly considers himself to stand with respect to his Maker! hence the grand source of that longing after a future state, where his knowledge will be consummated, and where he will no longer "see through a glass darkly"—notions at once the result and reward of his reason, and which raise man far above all other animals.

We have endeavoured to illustrate the argument of design, by one of those obvious examples of the adaptation of means to an end among the objects of nature, which impress on man a belief in the existence of design, and of a Designer. Compared, however, with the extent of creation, the instances, numerous as they appear, in which man is thus able to trace the designs of his Creator, are really few. Man not only sees means directed to certain ends, but ends accomplished by means, which he is totally unable to understand. He also sees, everywhere, things, the nature, and the end, of which, are utterly beyond his comprehension; and respecting which, he is obliged to content himself with simply inferring the existence of design.

The argument of design, therefore, in its general sense, embraces at least three classes of objects:—

1. Those objects, regarding which, the reasoning of man coincides with the reasoning evinced by his Creator; as in the simple adaptation of clothing above mentioned: or those objects, in which, man is able to trace, to a certain extent, his Creator's designs; as in various phenomena amenable to the laws of quantity.

2. Those objects, in which, man sees no more than the preliminaries and the results, or the end and design accomplished: without being able to trace, through their details,

the means of that accomplishment; as in all the phenomena and operations of chemistry.

3. Those objects, in which, design is inferred, but in which the design, as well as the means by which it is accomplished, are alike concealed; as in the existence of fixed stars; of comets; of organic life: and indeed in all the great and more recondite phenomena of nature.

The intention of these Treatises is to point out the various evidences of design, among the objects of creation; and to deduce from them the existence and the attributes of the Creator. The following pages are occupied, more particularly, with the illustration of the evidences of design, in objects belonging to the second of the three classes above-mentioned; with those, namely, in which design is apparent, though we cannot trace the means by which that design is accomplished.

CH. II.—OF THE RANK OF CHEMISTRY AS A SCIENCE; AND OF THE ARGUMENT OF DESIGN WITH REFERENCE TO CHEMISTRY.

"CHEMISTRY does not afford the same species of argument (in favour of design) that mechanism affords, and yet may afford an argument in a high degree satisfactory." This remark of the excellent Paley,* has been made by him with reference only to a particular subject; but the following sketch, pointing out the grounds on which chemistry as a science is founded, and the rank which chemistry holds among the departments of human knowledge, will at the same time show the general truth of the remark.

An elaborate inquiry into the origin and nature of human knowledge, would be quite misplaced here. We shall content ourselves with simply considering knowledge as of the two kinds described in the preceding chapter, viz.: a knowledge of what must be; that is to say, of what we cannot conceive either not to exist, or to exist otherwise than as it is; which knowledge is therefore founded upon reason (or necessity): and a knowledge of what simply is, but how or

* Natural Theology, chap. vii.

why we know not; for the existence of the objects of which knowledge, therefore, we have no authority beyond our own consciousness, or the evidence of our senses.

Of these two kinds of knowledge, the only instance of the first kind which particularly concerns us at present, is the knowledge of quantity, and its relations in general: to the second kind of knowledge, belong those natural phenomena, the consideration of which constitutes the proper subject of the present volume.

The fundamental differences between these two great branches of human knowledge, as well as their consequences, cannot perhaps, be more strikingly illustrated, than in the following familiar comparison by a celebrated writer. "A clever man," says Sir J. Herschel, "shut up alone, and allowed unlimited time, might reason out for himself all the truths of mathematics, by proceeding from those simple notions of space and number, of which he cannot divest himself without ceasing to think: but he would never tell by any effort of reasoning, what would become of a lump of sugar, if immersed in water; or what impression would be produced on his eye, by mixing the colours yellow and blue;"* results which can be learnt only from experience.

Thus, then, the extremes of human knowledge may be considered as founded, on the one hand, purely upon reason; and on the other, purely upon sense. Now, a very large portion of our knowledge, and what in fact may be considered as the most important knowledge we possess, lies between these two extremes, and results from a conjunction of reasoning with sense; that is to say, consists of the application of rational principles to the phenomena presented by the objects of nature.

With respect to knowledge founded upon reason, we are so constituted, that whether we contemplate, in the abstract, those primary notions of space, time, and force, above alluded to; or whether we view those notions in connexion with the objects of sense around us, we cannot divest them of quantity, which seems to be involved in their very essence. Quantity and its relations, therefore, in some shape or other, enter as a necessary element, into by far

* Discourse on the Study of Natural Philosophy, p. 76.

the greater portion of human knowledge. Now the primary relations of quantity are exceedingly simple; one quantity may be equal to another; or it may be greater or less: but we can conceive no other relation. Hence all the operations of the mathematics—the science of quantity and its relations—however abstruse and complicated they appear, can be ultimately resolved into addition and subtraction.

It is chiefly then through the medium of the relations of quantity, that we are enabled to reason in a satisfactory manner, upon the objects of sense. For as everything in nature, or what is the same thing to us, every sensation produced by one natural object, as compared with the sensation produced by another, must be either equal or unequal, similar or dissimilar: the whole of the objects of sense are capable of being subjected, more or less perfectly, to the laws of quantity. This is effected in various ways, and by various artifices; but chiefly through the intervention of certain natural or assumed units, and standards of resemblance, as a second in time, or a foot in space; and in proportion to the definite character of these units, or standards, or to their more or less satisfactory application, will the resulting branch of knowledge be more or less of a mathematical character; and will be more or less rational and perfect.

By contemplating in the abstract, the boundless relations of time and of space, where no end can be conceived to addition and subtraction, we arrive at the only notions of infinity of which our nature seems capable. These notions once obtained, the obvious and necessary existence of cause, within the narrow sphere of our observation, naturally leads us to inquire, can this cause be infinite? And thus we are led by degrees, but irresistibly, to the sublimest of all conclusions: that a Cause or Agent, in every way commensurate with infinity—omniscient and omnipresent, eternal and omnipotent, must exist—in other words, a GOD.

Compared, however, with infinity, and even with the objects of nature as they visibly exist around us, our actual knowledge of time and of space, is exceedingly limited. Like travellers on an extended plain, we see what is going on around us at the present moment; but the distant and

the very near, the past and the future, are alike unknown to us. A few millions of miles, for example, or a few thousand years, comprise the utmost we know of space and of time. On the other hand, beyond the fraction of an inch, or of a second, everything belonging to space and to time is inappreciable by our senses. Yet beyond these limits, we know that myriads of portions of space and likewise of time must exist, too vast or too minute to be referred to our imperfect standards. Let us, for instance, take the distance of the nearest fixed star. This distance, we are assured by astronomers, is so great, that the utmost measure we can apply to it—the diameter of the earth's orbit, a space of no less than 192 millions of miles—is absolutely too little to measure it by—is, in fact, contained within it so many times, that the number cannot at present be certainly counted! On the other hand, we shall presently find, that the molecules of matter of which the objects we see around us are composed, are so minute, that a measure scarcely appreciable by the unassisted sight —the thousandth part of an inch, for example—is vastly too large to compare them with, and may, in fact, comprise millions of them!

Experience, the great and ultimate source of all the knowledge we possess of those portions of nature, to which our senses and faculties are limited, may be acquired in two ways: by simple observation, and by experiment; that is, either "by noticing facts as they occur, without any attempt to influence the frequency of their occurrence, or to vary the circumstances under which they occur;" or, "by putting in action causes and agents over which we have control, and purposely varying these combinations, and noticing what effects take place."* Now in all the higher departments of knowledge, the objects of which are principally matter, and its motions in the aggregate: the information we can acquire by one or both these means is so complete, and at the same time so favourable to the application of the relations of quantity, that the resulting sciences have all the certainty of abstract truths themselves. But when the knowledge we possess

* Herschel's Discourse on the Study of Natural Philosophy, p. 76.

of objects is wholly sensible, and in no way commensurate, or only very imperfectly so, with their quantity, here it is that uncertainty begins; for though we may be able to trace the apparent cause and effect of a particular phenomenon; the most minute and careful observation and experiment often give us but little insight into the connexion between the two, and generally fail us altogether. The origin of this failure is to be sought for, in the limited extent of our faculties: and particularly, in our complete ignorance of the nature of that mysterious communication, which we maintain with the external world, through the medium of sensation. In two of the senses, indeed, seeing and hearing, we are able to trace the intermediate train of phenomena, between the external object producing the sensation, and the sensation itself, and even to form some idea of the remote cause of the sensation; but in the other two senses, tasting and smelling, the whole is involved in mystery from beginning to end.

Thus, when a bell is struck, philosophers have satisfactorily demonstrated that a vibratory motion, excited in the bell, and depending upon its elasticity, is communicated to the air in contact with the bell, and through this medium is propagated to the ear; in which organ, we know not why, the sensation of sound is excited. Circumstances very similar have been supposed to take place with respect to light; and *undulæ*, (or something obeying the laws of *undulæ*,) have been demonstrated to exist, and to be propagated from the luminous body to the eye; thus the remote cause of sound, and probably of light, is proved to be motion. But in the cases of tasting and smelling the circumstances are altogether dissimilar; here the sapid and odoriferous matters are brought at once into actual contact with the sentient organs, and the sensations are the consequence, without any intermediate train of phenomena; at least any, that we can appreciate. What it is, therefore, in an acid, or a rose, for example, analogous to motion in the bell, which produces the sensations we call sour and sweet, we know not, and probably never shall know; because the laws and relations of quantity are here either totally inapplicable, or can be only indirectly and most imperfectly applied.

These observations are introduced principally with refe-

rence to the department of knowledge we have at present to consider. Almost all of what are denominated the Chemical properties of bodies, are objects of taste and of smell, rather than of sight and of hearing. Hence these properties admit only of the indirect application of the laws of quantity; and are the result, not of reason, but solely of experience. Indeed, so much is chemistry the creature of actual experimental research, that its simplest truths have seldom been anticipated *à priori*. Thousands of years of observation and experience, for example, had not taught mankind that water is composed of two primary gaseous elements; much less, the proportions in which those elements combine to form water. Nay, even now the fact has been established upon the clearest evidence, we are unable to explain why it is so, or even to comprehend the nature of the union or its result. In all chemical operations, therefore, (to adopt the language of Paley,)—" our situation is precisely like that of an unmechanical looker-on, who stands by a machine, as a corn-mill, a carding-machine, or a threshing-machine, the fabric of which is hidden from his sight by the outside case; or if seen, would be too complicated for his uninformed understanding to comprehend. And what," continues this energetic writer, " is that situation? Ignorant as he is, he does not fail to see that certain materials, in passing through the machine, undergo remarkable changes; and what is more, changes manifestly adapted for future use. Is it necessary that this man, in order to be convinced that design, that intention, that contrivance, have been employed about the machine, should be allowed to pull it to pieces to study its construction? He may indeed wish to do this for many reasons; but for all the purposes of ascertaining the existence of counsel and design in the formation of the machine, he wants no such intromission or privity. What he sees is sufficient. The effect upon the material, the change produced in it, the utility of that change for further applications abundantly testify, be the concealed part of the machine, or of its construction, what it will, the hand and agency of a contriver." *

We have thus attempted to point out the rank which

* Paley's Natural Theology, Chap. vii. condensed slightly, but the argument strictly adhered to.

chemistry holds among the departments of human knowledge, and the kind of evidenee which it furnishes in favour of design: the whole argument may be briefly reeapitulated as follows:—ehemistry is a department of knowledge founded solely on experience, for the phenomena of whieh we ean assign no reason. But although the intimate nature of chemieal changes be unknown to us, we see them manifestly direeted to eertain ends; henee, as things direeted to eertain ends, where the whole of the intermediate phenomena ean be traeed and understood, always imply design; we naturally infer design in ehemieal ehanges obviously so direeted, even although we may not be able to understand their intimate nature.

Sueh is the state in which Paley has left the argument; and while we admit that, even in its most perfeet form, it is less satisfaetory than arguments founded on mechanism; we have always thought that our exeellent author has not made quite so mueh of his subjeet as he might have done; and that the very imperfeetions and diffieulties of ehemistry, and of the allied branehes of knowledge, give them some advantages over meehanism itself. When a series of wheels or of levers are arranged in a eertain order, they must move in a eertain way, and produee a eertain effect, whieh ean be foretold exaetly. In sueh a ease, we may admire the skill and ingenuity of the eontriver, or perhaps feel astonished at his power; but we seareely do more: for mueh of the effect is lost in the apparent neeessity of the result; and the eonseiousness that, under the eireumstanees, nothing else eould have happened. When the Deity, therefore, operates through the medium of meehanism, He appears almost too obviously to limit His powers within the trammels of neeessity; but when he operates through the medium of ehemistry, the laws of whieh are less evident, and indeed for the most part unknown to us, His operations, partaking more of the eharacter of those of a free agent, appear of a higher order, and are more striking and wonderful. Do not, for instanee, those extraordinary and mysterious ehanges constantly going on around us, beneath us, within us, derive no small additional interest from the very eireumstanee of their not being understood? Just sueh an interest, to revert to the argument of Paley, as the unmechanical looker-on

feels in the operations of a corn-mill, a carding-machine, or a threshing-machine; and to which he who is well acquainted with the mechanism, is a stranger? Certainly this is the case. Obvious mechanism, though well suited to display the intelligence and design of the contriver, is not always so well adapted for arresting the attention of the observer; its very obviousness, in some measure, depriving it of its interest. But when we see the same Contriver, besides the most beautiful and complicated mechanism, employ other means utterly above our comprehension, though evidently most familiar to Him; the employment of these means is not only calculated to arrest our attention more forcibly, but at the same time to impress us with more exalted notions of His wisdom and power.

There yet remain one or two other points to be briefly considered, before we proceed to our subject. In the first place it may be asked, Do those extraordinary changes which appear to be constantly going on in bodies around us, indicate real and substantial changes in the bodies themselves; or are these changes mere phantasms and creations of the organs of sense, through which we become acquainted with them? The discussion of this question will probably be considered by most readers as superfluous; but for the sake of those (if there be any) who entertain doubts on the point, it may be remarked, that our sensations, though admitted to be mere signals or indications, bearing little or no analogy to the causes by which the sensations are produced, and therefore throwing little light on their nature, do nevertheless represent real and substantial operations of some sort, in bodies themselves. This reality might be proved, were it necessary, by a variety of arguments; but perhaps one of the most striking arguments in favour of the reality of chemical changes, may be deduced from the subserviency to them, of those mechanical contrivances and operations every where existing in organised beings. At least half the mechanism in a living animal, is subservient to the chemical changes constantly going on in it, and necessary to its existence. Take, for instance, the circulation of the blood: what a complicated apparatus is here employed for the simple purpose of exposing the blood to the action of the

air in the lungs, in order that it may there undergo some chemical change. Now, surely no one can reasonably doubt that this chemical change is as much a reality as the mechanism by which the chemical change has been accomplished; and if one chemical change be admitted to be a reality, must not all the others be equally real?

Finally, if there be any one who denies the existence of design, and sees nothing in all the more obvious arrangements and order around him, but the necessary results of what he chooses to denominate "the laws of nature;" let him calmly and deliberately consider the facts brought forward in the following pages: and if he can witness unconvinced all the numerous instances of prospective arrangement clearly made with reference to things not yet in existence; all the beautiful adjustments and adaptations of noxious and conflicting elements most wonderfully conspiring together for good; and, lastly, the subversion of even his favourite "laws of nature" themselves, when a particular purpose requires it: if, we say, he can witness all these things, and still remain incredulous of the evidences of design; his mind must be most singularly constituted, and apparently beyond the reach of conviction.

CH. III.—OF MATTER AND OF PHYSICAL AGENTS IN GENERAL; AND OF THEIR MUTUAL RELATIONS.

"God has been pleased to prescribe limits to his own power, and to work his ends within those limits. The general laws of matter have perhaps the nature of these limits; its *inertia*, its reaction, the laws which govern the communication of motion, of light, of heat, of magnetism and electricity, and probably of others yet undiscovered. These are general laws, and when a particular purpose is to be effected, it is not by making them wind and bend and yield to the occasion, (for nature with great steadiness adheres to, and supports them,) but it is, as we have seen in the eye, by the interposition of an apparatus corresponding

with these laws, and suited to the exigency which results from them, that the purpose is at length attained. As we have said, therefore, God prescribes limits to his power, that he may let in the exercise, and thereby exhibit demonstrations of his wisdom. For then, *i.e.* such laws and limitations being laid down, it is as though one Being should have fixed certain rules; and, if we may so speak, provided certain materials; and afterwards have committed to another Being, out of these materials, and in subordination to these rules, the task of drawing forth a creation: a supposition which evidently leaves room, and induces indeed a necessity, for contrivance. Nay, there may be many such agents, and many ranks of these." *

This admirable passage from Paley so exactly expresses our opinions regarding matter and physical agents, that as in a former instance, we have chosen it as a text for illustration. We shall proceed, therefore, to take a summary view of the laws by which matter and physical agents act and react on each other; or, in the words of Paley, attempt to define "the limits which the Deity has prescribed to His own power."

That matter, and the power of moving matter exist, both within our own corporeal frames, as well as in the world around us, we cannot doubt, without doubting our own existence. By evidence equally irresistible, we are impelled to the belief, that matter, and the power of moving matter, though everywhere conjointly existent and exerted, must be essentially different. In other words, that matter does not move in virtue of any property necessarily belonging to it as matter; but that matter was first created and set in motion by the Deity when he formed the universe; and that the motion then originally imparted to it, is still retained, and will continue to be retained, by matter "till time shall be no more."

The faculty of deducing these important inferences from the phenomena of nature, is our peculiar privilege: but at present we can go no further. Of the positive or abstract nature of matter and of power, any more than of the positive and abstract nature of the Deity himself, we know

* Paley's Natural Theology, chap. iii.

absolutely nothing. Such knowledge, doubtless for the wisest purposes, has been placed beyond the pale of the human intellect, and is probably even incompatible with our nature. Our present line of duty therefore is clearly defined. We must study natural phenomena as they have been revealed to us; and hope,—what is not unreasonable, and cannot be unlawful,—that the information thus acquired will the better fit us for that fulness of knowledge to which we aspire.

In conformity with these views, we shall avoid abstract speculations; and taking for granted that matter and power exist, and are different; assume their relationship to each other to be that of passion and agency. According to this assumption, matter is entirely passive; while the forces by which it is moved are, as it were, personified, *i. e.*, supposed to be wielded by subordinate and delegated existences, capable of exerting physical force according to certain laws, and within certain limits, prescribed by the Deity; of whose will, therefore, they are the immediate executors. In other words, to use the language of Paley, this assumption regards physical agency as exerted by "subordinate beings, to whom the Deity, after having laid down certain laws, and furnished certain materials, has delegated the task of drawing forth a creation."

CH. IV.—OF MATTER IN GENERAL.

Of the positive and abstract nature of matter, as already stated, we know nothing. We contemplate matter here as it exists around us, and particularly with reference to its mechanical properties. For this purpose we shall take a short view—first, of the Mechanical Divisibility, and of the Molecular Condition of matter; and—secondly, of the Forms of Aggregation assumed by material molecules. We shall then endeavour to show that the molecular condition of matter is not a necessary condition; and consequently that the molecular condition of matter cannot be proved to be eternal.

§ 1.—*Of the Mechanical Divisibility, and of the Molecular Condition of Matter.*

Although natural bodies differ infinitely in their qualities, and are in general very heterogeneous in their composition; many are composed of homogeneous matter, and vary only in magnitude, from others. Magnitude or Quantity, therefore, within the limits cognizable by our senses, has nothing to do with the properties of bodies; and how much soever we may subdivide a homogeneous body, still its visible component parts will all be similar to the original mass. Thus the minute but sensible portions into which a quantity of marble, of water, or even of air may be subdivided, are all found to possess precisely the same properties as the original aggregates. Nor do we stop at the limits defined by our organs of sense. We infer that the divisibility of matter may be carried much beyond these limits. That marble, water, and air, for instance, may be subdivided into parts so minute as cease to be cognizable by us. But where inference thus supplies the place of actual observation, we are compelled to change our logic. No longer able to appeal to the evidence of our senses for the truth of our conclusions, we have recourse to facts and arguments remotely bearing on the subject; and thus endeavour to give our inference the utmost probability it will admit. We make this remark, no less for the sake of illustrating what has been already said regarding the rank of chemistry as a science, in the second chapter, than of introducing the following observations on the further subdivision of particles obtained by mechanical means into Ultimate Particles, Atoms, or Molecules; that is to say, into parts so minute as not to admit of further subdivision without destroying their identity.

Viewed mathematically, matter, or rather space, may be conceived to be divisible *ad infinitum;* at least no limits can be assigned beyond which the subdivision of space may not necessarily proceed. But there cannot be any doubt that matter as it exists in the world around us is composed of ultimate particles, atoms, or molecules, incapable of further division without change of their properties. Thus although we cannot detach individual molecules from a

mass of marble, water, or air; yet these substances may, by various artifices, be so subdivided that individual molecules lose their identity, and become converted into two or more principles, possessing the character of elements. We say elements; because these component principles of marble, water, and air being incapable of further molecular subdivision, may be justly regarded as primary elements; and we shall find hereafter that all the infinite variety of objects in the world may in fact be reduced to a few of such primary elements.

The following remarks will serve to convey to the general reader some idea of the magnitude of the molecules of which bodies consist; and to show how infinitely their minuteness surpasses the limited powers not only of our senses, but almost of our conception. We shall select for illustration, a single body from each of the kingdoms of nature.

As an instance from the mineral kingdom, we may quote from Dr. Thomson, who has shown that a molecule of lead cannot weigh more than the 1-310,000,000,000th, nor an ultimate molecule of sulphur more than the 1-2,015,000,000,000th of a grain, and probably a great deal less; and that the size of the molecule of lead cannot surpass, and is probably much smaller, than the 1-888,492,000,000,000th of a cubic inch!*

The vegetable kingdom presents us with innumerable instances, not only of the minuteness of material molecules, but of their activity, in the almost incredibly rapid development of cellular structure in certain plants. Thus the *Bovista giganteum* (a species of fungus,) has been known to acquire the size of a gourd in one night. Now, supposing with Professor Lindley, that the cells of this plant are so much as the 1-200th of an inch in diameter, a plant of the above size will contain no less than 47,000,000,000 cells; so that, supposing the plant to have grown in the course of twelve hours, its cells must have been developed at the rate of nearly 4,000,000,000 per hour, or of more than sixty-six millions in a minute!† and when we consider that every one of these cells must be composed of innumerable molecules,

* System of Inorganic Chemistry, I. 7.

† Introduction to Botany, p. 7.

each one of which is again composed of several elementary molecules; we are perfectly overwhelmed with the minuteness, and number of the parts, employed in this singular production of nature.

But the animal kingdom perhaps presents us with still more striking instances than these. Thus animalcules have been discovered whose magnitude is such, that a million of them do not exceed a grain of sand; and yet each of these creatures is composed of parts as curiously organized as the structure of the largest species. These animalcules have life and spontaneous motion, and are endowed with feeling and instinct; in the liquids in which they live, they are observed to move with astonishing speed and activity; nor are their motions blind and fortuitous, but evidently governed by choice, and directed to an end. They consume food and drink, from which they derive nutrition; and are therefore furnished with a digestive apparatus. They have great muscular power, and are provided with limbs and muscles of strength and flexibility. They are susceptible of the same appetites, and obnoxious to the same passions, as the largest animals. Must we not conclude that these creatures have hearts, arteries, veins, muscles, sinews, nerves, circulating fluids, and all the concomitant apparatus of a living organized body? and if so, how inconceivably minute must these parts be?* If a globule of the blood of these animalcules bears the same proportion to their whole bulk, as a globule of our blood bears to our magnitude, what power of calculation can give an adequate notion of its minuteness?†‡

We have thus endeavoured to convey some conception of the magnitude of the ultimate particles, atoms, or molecules,

* More recent researches tend to show, that the structure of animalcules is more simple than was formerly supposed; and that the localization of function in special organs or tissues does not generally occur. Many so-called animalcules are now referred to the vegetable kingdom. The argument is not, however, essentially affected hereby.—G.

† Cabinet Cyclopædia, Art. Mechanics, p. 13.

‡ It is most probable that animalcules have no blood-globules; the functions which they are supposed to perform being effected by contact with the aerating medium in which they live; from their extremely minute size, this contact being almost direct.—G.

of which bodies are composed; but though we have succeeded in showing that these molecules cannot exceed a certain size; we are by no means certain that many others are not in reality much less—indeed a great deal less, than the least magnitude of which we have endeavoured to convey a conception: yet notwithstanding this inapproachable minuteness, the component molecules of bodies retain, in the highest degree, all the characters of matter; and moreover possess peculiar properties, different from the mere mechanical properties of material particles, and termed molecular properties; as we shall hereafter endeavour to explain.

§ 2.—*Of the Forms of Aggregation of Material Molecules.*

Matter in general is known to us in three forms of aggregation only, viz. the solid, the liquid, and the gaseous (the latter form including vapours, and æthers).

These three forms of material aggregation alike depend on the molecular condition of matter just described; but, as will be subsequently shown, the molecular energies in the different forms of aggregation are differently exerted. In their well-marked states, the three forms of material aggregation are sufficiently distinct; though the whole gradually run into each other—the solid into the liquid, and the liquid into the gaseous, by grades so imperceptible, that in many instances it is not easy to say where one ends and the other begins.*

The notions the mechanical or natural philosopher employs in reasoning on these forms of aggregation are—of a solid, that all its parts are indissolubly and unalterably connected, and impenetrable; so that the relation of the parts cannot be changed, or one part be set in motion without all the rest:—of a liquid, that all its parts are freely moveable among one another, but that it is not

* It may be proper here to observe, that some bodies, as water for instance, are capable of existing, under all ordinary circumstances, in that imperfectly gaseous form denominated vapour. Thus even ice gives off vapour rapidly, as we shall find hereafter.

dilatable or compressible by mechanical means:—of a gas or aeriform body, that all its parts are not only freely moveable among one another, but that it is compressible and dilatable without limit. Strictly speaking, however, there are no objects actually existing in nature which completely conform to these definitions: no solid, for instance, absolutely hard and impenetrable; no fluid not compressible and dilatable; no gas compressible or dilatable without limits: and these circumstances are evidently the necessary result of the peculiar constitution of all natural objects described in the preceding section. Thus bodies composed of innumerable molecules, though apparently solid, can scarcely be imagined to be free from interstices or pores. Accordingly we shall find that all natural solids, when submitted to pressure, undergo condensation, and occupy less space than before. The same remarks may be made with respect to liquids. On the other hand, gaseous matters, also supposed to consist of innumerable molecules, cannot for that reason, be infinitely compressible.

§ 3.—*Arguments founded on the Molecular Condition of Matter, in proof that the molecular condition of matter has not always existed, but must have been created by an Intelligent Being.*

The arguments relating to the origin and object of the molecular condition of matter, may be classed under the three following heads:

First,—that matter has not always existed in its present molecular condition:

Secondly,—that matter could not have existed in its present molecular condition by chance.

Thirdly, and consequently,—that the present molecular condition of matter must have been the work of a voluntary and intelligent Being. Other deductions might be made from the molecular condition of matter, some of which will be subsequently alluded to: at present we confine our arguments to grounds admitting of no controversy.

In the first place, the molecular condition of matter,

seems to prove beyond a doubt, that matter cannot have eternally existed in its present state.

Although we can form no idea of the mode in which the present economy of the universe could be sustained without the intervention of matter in its molecular condition, our ignorance on this point does not prove, nor can we prove by any other train of argument, that the molecular condition of matter is a necessary condition. On the contrary the existence of matter in some other condition than that of molecule, is not an impossible, perhaps not an improbable, supposition. No one, for instance, can assign a valid reason why all the matter in the universe could not be collected into a few impenetrable masses, or even into a single mass. But if the existence of matter in some other condition than that of molecule be possible, the molecular condition of matter cannot be necessarily an eternal condition—on the general grounds, that eternal existence implies exemption from the possibility of change. The molecular condition of matter, therefore, cannot be proved to have existed from eternity, and consequently must have had a beginning.

The above remarks apply to the molecular condition of matter in general; but we shall see hereafter, that chemists recognize upwards of fifty forms of matter, all of an elementary character; at least, we cannot at present say, that one of these forms is less elementary than another. Again, the number of molecules in each of these primary elements, great as it is, is limited; the properties of the molecules also are fixed and definite;—circumstances which throw further insurmountable difficulties in the way of the supposition, that the whole of the primary material elements have existed, as they now exist, from eternity. For how has it happened, it may be asked, that the number and properties of these primary elements, or that the number of the molecules of which they consist, are exactly what the economy of nature requires; and are neither greater, nor less, nor different? How has it happened, that things supposed to be infinite in some respects, should be finite and limited in those respects, in which we are actually able to trace them; nay, what is more, that these things should most luckily be finite and limited, just where they appear

to be required to be so? He who can satisfactorily answer these questions, may contend with some prospect of success for the eternity of matter, and of its properties, in their present form. In the mean time, we assert without fear of contradiction, that the molecular condition of matter is decidedly artificial; or to use the words of a celebrated writer, that material molecules have all "the essential characters of a manufactured article,"* and consequently are not eternal.

Secondly. If the present molecular constitution of matter has not always existed, it must have been produced at some time, by some cause superior to itself. Now this cause must have operated either accidentally and by chance; or voluntarily and under the influence of a will.

With respect to the first of these alternatives, viz. chance; the endless repetition of similar parts presented by the molecular condition of matter, seems absolutely to preclude this opinion. Do we not consider it a subject of wonder to see even two or three things by chance alike; as for example two or three human faces? Should we not consider the man absolutely mad, who attributed the uniform, or manœuvres, of a regiment of soldiers to chance? and can we then resist the argument in the infinitely stronger shape, in which it is here presented to us? Thus, as the idea of chance seems too monstrous to be entertained for a moment by any rational being, we are impelled irresistibly to the other conclusion; viz. that the cause or agent who formed the molecular condition of matter, was a voluntary agent, or Being; and moreover, that this Being possessed a power commensurate with his will.

Thirdly. The agent or Being who constructed the wonderful system we have been considering, must have been as intelligent, as he was powerful.

We infer intelligence in an agent from the fitness and adaptation to certain ends exemplified in his works. When, for instance, we see a machine admirably fitted for the office it performs; we infer that the maker of that machine must have possessed intelligence. Now, if we judge of the molecular condition of matter by this rule: we shall find,

* Sir J. Herschel on the Study of Natural Philosophy, p. 38.

that there is not only the most extraordinary fitness and adaptation to circumstances, displayed in its arrangements, as far as we can understand them, but beyond what we can understand;—that the maker of this system, must not only have possessed intelligence; but intelligence infinitely surpassing our own. Even the very adoption of the molecular condition of matter may be considered as indicating intelligence of the highest kind; for of all the conditions of matter that can be conceived to exist, the molecular seems best adapted to the purposes of creation.

Such are a few of the leading facts deducible from the molecular condition of matter. And when we contemplate all the wonderful and mysterious phenomena dependent on this simple condition, what a still more sublime idea does the contemplation convey to us of the wisdom and power of that Being who first contrived, and still directs the whole! When or where, do we naturally exclaim, does this Being exist? Whence His wisdom? Whence His power? There is, there can be, but one answer to these inquiries. The Being who first contrived and still directs all these things must have existed from eternity—must have been omniscient—must have been omnipotent—MUST HAVE BEEN GOD!

CH. V.—OF AGENCY IN GENERAL.

WE have said that our experience and feelings irresistibly impel us to the belief that a Faculty of Agency, *i.e.* a faculty of exerting physical force exists, not only in the world around us, but within ourselves. Further observation and reflection also teach us that this faculty of agency is of two kinds: viz. a general faculty of agency existing throughout the universe, and known to us by the exertion of physical forces according to fixed laws: and a limited faculty of agency existing within ourselves, and known to us by the exertion of physical forces either in obedience to our own will, as intelligent agents; or in

obedience to a will different from our own, and obviously appertaining to a different intelligent agent. We shall therefore, consider the subject of agency in general, under the two following heads or sections:

Section I.—Agency exerted throughout the universe and recognized by the exertion of physical forces according to fixed laws; Unintelligent, Mechanical, or simply Physical Agency; and Section II. Agency recognized by the exertion of physical forces in obedience to the will of an Intelligent Agent; Intelligent Agency.

§ 1.—*Of Unintelligent or Physical Agency.*

Physical agency, or the exertion of physical forces, is so associated with matter, that to us these forces appear to possess all the characters of material properties, without which, as we have said, we could not conceive matter to exist. Hence, as physical agency is known to us only through the medium of matter, physical forces are naturally divided into two orders, viz., 1. Mechanical forces, strictly so called; or, those forces exerted in connexion with visible aggregates of matter: and, 2. Molecular forces, or those forces operating in connexion with the invisible and ultimate particles, atoms, or molecules of which we have shown matter to consist. We shall endeavour to explain in the present chapter these two great orders into which physical forces are thus naturally divided. The detailed consideration of the exertion of physical forces by Intelligent Agents more properly belongs to the last Book.

1. *Of Mechanical forces.* In contemplating mechanical operations as displayed by the reciprocal motions of two material masses, we recognise in all instances the exertion of two co-ordinate and mutually opposing forces. These forces are apparently exerted in different modes, and have in consequence acquired different appellations; but a little attention shows that virtually between any two given masses of matter, forces are exerted in two directions only; viz. *a.* Centripetally, *i. e.* causing the mutual approximation of two masses of matter; and *b.* Centrifugally, *i. e.* causing the

mutual separation of two masses of matter. The general nature and relation of these two forces may be thus briefly illustrated.

a. Two detached masses of matter, when unimpeded, move toward each other in virtue of a force mutually exerted between themselves, and termed an attractive force. This Attractive, Centripetal, or Gravitating force belongs to every atom as well as aggregate of matter in the universe, and is probably coeval with the creation of matter. The attractive force of matter therefore might have existed before the Deity endowed it with motion, and thus caused its separation into masses.

b. Two detached masses of matter, however, do not rush together instantaneously; but, as will presently be shown, their motions toward each other occupy time; and are slower as the masses are larger, and the further they are separated. Thus, besides their mutually attractive force, two detached masses of matter exert a mutually opposing force; which mutually opposing force retards, or has a tendency to counteract, their union. Now, to the existence of this opposing, or Centrifugal force (termed in the sense we are contemplating it, the Inertia of matter*) we owe the stability or rather the existence of the present order of things; for did an attractive force alone exist among material bodies, they would all necessarily rush together at once, and cause the instantaneous collapse of the universe. The opposing or centrifugal force of matter must be coeval with the motion of matter, and consequently with the present order of things; but cannot, like the attractive force of matter, be supposed to have had a prior existence.

The preceding is the view of the two forces of gravitation

* Many objections have been offered to the term *vis inertiæ* adopted by Newton. Indeed, to speak of mere inertia or inactivity as a force, is obviously absurd. We have always agreed with those who think that the term inertia has been unfortunately chosen; since inertia expresses only one quality, as it were, of that which is attracted, and which reacts in return. But we fully acquiesce in the opinion that whatever resists attraction or reacts, is as appropriately named a force in a certain sense of that term, as that which attracts or acts; and such faculty of resistance or opposition, is in all instances virtually considered by the mathematician as a force, whatever he may choose to designate it.

which has been usually adopted by mechanical philosophers, since the time of Newton. In a subsequent chapter we shall again have occasion to refer to them. At present it is sufficient to remark that the developement of the mutual relations and operations of these forces by Newton has constituted one of the proudest triumphs of the human intellect.

There is, however, another view of this subject, which may be briefly mentioned here, and which, while it does not exclude Newton's principles; may, from its more general character, be said to comprehend or include them. This view or hypothesis, like that of Newton, supposes an attractive or centripetal force to have been originally imparted by the Deity to matter. The opposing or centrifugal force of matter also, as in the hypothesis of Newton, is supposed to be conveyed through, or rather to result from its motion; but here the analogy between the hypothesis of Newton, and the hypothesis we are now considering, terminates. The hypothesis we are are now considering supposes, that besides an attractive force, a tendency to motion on itself as a centre, or rather, on its own axis, was likewise imparted by the Deity to every material molecule and aggregate in the universe, when He called the present creation into existence: that while the attractive force of matter, *cœteris paribus*, increases as its quantity increases, the velocity, and consequently the intensity of the force resulting from the velocity of such molecule or mass of matter, *cæteris paribus*, increases as its quantity diminishes: that owing to the comparative state of rest in which, according to this hypothesis, the Poles of all molecules and masses in motion on their axes exist, the aggregate amount of the force of attraction in the universe, necessarily exceeds the aggregate amount of the antagonist or centrifugal force resulting from rotatory motion: and finally, that this excess of the attractive over the repulsive force in nature, constitutes tho attractive force of gravitation contemplated at present by mechanical philosophers.

2. *Of molecular forces.* Of the nature of the forces exerted by matter in the molecular condition, there has been, and still is, great diversity of opinion. This difference of opinion arises from various causes; but principally from the

minuteness of the individual molecules of which matter consists, and the consequent minute and imperceptible character of the motions of such molecules. Moreover, in different instances molecular forces apparently assume so many different forms, that it becomes a work of great difficulty, if not of impossibility, in the present state of our knowledge, to reduce them to a uniform system. Molecular forces, however, are usually admitted to resemble the forces of gravitation above described, so far as universally to consist of two mutually opposing or antagonist forces; the one of an attractive character and corresponding in every respect to the attractive force of gravitation, with which it is probably identical; the other of a repulsive character, and more or less resembling the centrifugal force of gravitation as conveyed through the inertia of matter. Molecular operations, however, as we have stated, are so numerous, multiform, and wonderful, that philosophers have not yet been able to reduce them all to the operation of the same two antagonist forces. They have been obliged, therefore, to frame other hypotheses, so contrived as to include certain groups of phenomena apparently linked together by some common principle. For instauce, the phenomena of light in motion, have been referred to the progressive transverse undulæ or waves excited in an elastic medium, or æther, supposed to pervade space. By the same hypothesis, an attempt has been made to explain some of the observed phenomena of heat in motion. According to this hypothesis the forces exerted at the limits of an individual undula or wave (or rather perhaps at the central points between the limits of two consecutive transverse undular motions), are necessarily exerted in opposite directions, and consequently bear a relation to each other, somewhat analogous to the antagonist molecular forces above mentioned. This favourite hypothesis of progressive transverse ætherial undulæ has hitherto been confined to the phenomena of light and of heat in motion; and seems to be little if at all applicable to the phenomena of electricity or chemistry. It can therefore be considered as an imperfect and partial hypothesis only, which will probably, at no very distant time, be set aside for one more comprehensive and rational.

As we have mentioned the undulatory hypothesis assumed to explain the phenomena of light and heat, it may not perhaps be improper to notice an hypothesis which has been recently framed to explain some other important molecular phenomena, viz., the cohesive and chemical, or electric phenomena of matter: we allude to the molecular hypothesis of Mossotti, which has been viewed with considerable favour by some philosophers.

The molecular hypothesis of Mossotti supposes that each molecule of matter is surrounded by an atmosphere of an ætherial fluid; that the atoms of the ætherial fluid repel each other; that the molecules of matter also repel each other, but with less intensity than the atoms of the æther; and that there is a mutual attraction between the molecules of matter and the atoms of the ætherial fluid. Hence, according to this hypothesis, when the molecules of matter are inappreciably near to each other, they exercise a mutual repulsion with a force which rapidly diminishes as the infinitely small distance between the molecules augments, till the repulsive force becomes at length evanescent. At this neutral point, where the repulsive force between the molecules of matter terminates and the attractive force commences, the molecules have neither a tendency to approach nor to recede from each other. Beyond this distance the attractive force between the molecules is supposed to go on increasing to a maximum, and the molecules throughout this range of increased attractive force, will in consequence have a tendency to approach each other. When the molecules are still further apart, the attractive force is supposed to diminish; and as soon as the distance between the molecules becomes so great as to be sensible, the attractive force between the molecules of matter assumes the same law as the attractive force of gravitation. Lastly, according to this hypothesis, on account of the unequal repulsions supposed to exist between the molecules of matter and the atoms of the ætherial medium surrounding these molecules, the molecules of the matter and the atoms of the æther attract each other with unequal intensities, and leave an excess of attractive force which is supposed to constitute the attractive force of gravitation.*

* Connexion of the Physical Sciences, by Mrs. Somerville, p. 122,

We have given these brief sketches as examples of the hypotheses which have been framed by philosophers, to account for the phenomena of molecular operations; but we candidly confess that we have no confidence in either of them, and, from their partial and artificial character, consider them as utterly unworthy to be ascribed to the Deity, whose primary laws are ever simple, general, and comprehensive. To us it appears, therefore, infinitely more probable and more consistent with Almighty power, to suppose that one primary set of laws was originally framed for matter under all circumstances of quantity; than to suppose that two primary and different sets of laws, the one adapted to matter in the mass, the other to matter in the molecule, should have been framed. For what in reality constitutes the distinction between matter in the mass and matter in the molecule, but the limited nature of our own organs, by which the comparison between the mass and the molecule is estimated? With a Being infinite in knowledge and power, no such distinction can for a moment be supposed to exist; and if no such distinction can exist, the supposition of a distinction of laws is not only unnecessary but absurd.

After this statement, we scarcely need observe that the molecular hypothesis we prefer is identical with the mechanical hypothesis before mentioned; viz., that two distinct antagonist forces were originally imparted by the Deity to all matter; that one of these forces is in its nature attractive, and increases as the quantity of matter increases: that the other of these forces is exerted by matter in motion on itself (or its axis); is of a repulsive nature, and increases in intensity (like the motion through which it is exerted) as the quantity of matter decreases; and finally, that the operations of the microcosm, or world imperceptible to our senses, are precisely identical with the operations of the macrocosm, or sensible universe.*

fifth edition. The reader who is interested may also refer to the lately resuscitated theory of Boscovich.

* It may be observed that philosophers universally admit the existence of the attractive force of matter in general, and that it is the same in kind and degree for matter in every condition and quantity; they only doubt about the opposing or repulsive force of matter. But is not the identity and universality of the attractive force of matter a powerful

The exertion of mechanical forces by matter, is usually known to us by its change of place—in short, by the motion of matter; which motion being either directly or indirectly cognizable by us, becomes as it were the index or signal of exerted force. A remarkable contrast, however, exists between the properties, as well as the relations to motion of the two primary antagonist forces of matter, which deserve to be briefly noticed.

A single molecule of matter at rest, though endowed with attractive force, could not display, and therefore could not be known to possess, such attractive force, without the presence of other molecules; but a single molecule in motion on its axis is statically self-potential; *i. e.* is capable of exerting centrifugal force without change of place, and without reference to the presence of other molecules. These essential differences between the two primary antagonist forces of matter affect their relations to motion: thus motion follows, or is the consequence of the exertion of the centripetal or attractive force of matter; while the existence of axis motion precedes, and is, as it were, immediately necessary to the exertion of the centrifugal force of matter. In other words, attractive force is the immediate cause of centripetal motion, *i. e.* the motion of two different portions of matter towards each other; axis motion the immediate cause of repulsive force, or centrifugal motion, *i. e.* the motion of two different portions of matter from each other.

From what has been stated it appears that in all the hypotheses which have been framed to explain molecular phenomena, there has been universally an assumption of two forces.* Now from the general unanimity of philo-

argument for the identity and universality of the opposing or repulsive force of matter!

* For the sake of illustration, it may be worth while to notice here the principal names which have been assigned to molecular forces under different circumstances. The forces concerned in the phenomena of light and heat, electricity and magnetism, are usually known as the forces of polarisation, polarising forces, &c. The forces on which homogeneity, or the union and separation of portions of the same matter depend, are called cohesive and divellent forces. The forces concerned in the phenomena of heterogeneity, or the chemical union and separation of portions of different matters, are denominated the forces of affinity, or of chemical attraction and repulsion, &c.

sophers on this point, how much soever they may have differed in others, we may safely assume, without entering into any lengthened argument on the subject, that one force is insufficient, and more than two forces are unnecessary, to explain molecular phenomena. All molecular operations, therefore, however complicated they may appear, are essentially dual, *i. e.*, depend on the exertion of only two mutually opposing forces—a most important conclusion, to which we shall have occasion to refer hereafter.

Finally, we would remind the reader that the primary attractive force and the rotatory motion of matter above described, are not to be regarded as properties necessary to the existence of matter; but as properties voluntarily superadded to matter by the Deity, when He first called the universe into existence. Moreover, as there are no other properties of which we are cognizant, we may suppose these properties to have been constituted the sole representatives of His power and executors of His will in the material world; in other words, as already stated, these properties or physical forces have operated, and will continue to operate according to certain prescribed and unalterable laws, "till time shall be no more." Hence all subordinate or secondary agencies can accomplish their particular purposes only by the aid of appropriate machinery adapted to these physical forces of matter; or, as happily expressed by Paley, "when a particular purpose is to be effected, it is not by making the laws of matter wind and bend and yield to the occasion; but it is by the interposition of an apparatus corresponding with those laws, and suited to the exigency which results from them, that the purpose is at length attained."

§ 2.—*Of intelligent Agency.*

To prevent misconception, we shall explain at the outset the sense in which the expression Intelligent Agent is employed in the following pages.

The epithet Intelligent is intended to convey the meaning that the being to whom it is applied, possesses intelli-

gence or Knowledge. Now the knowledge here understood, is supposed to include all the usual and necessary elements of knowledge in general; that is, not only the knowledge or consciousness in the being, of proper and individual existence, and of the existence of other beings exterior to itself; but also the faculties of discriminating, comparing, and judging, in a greater or less degree, among the objects known. But mere knowledge is not enough of itself to constitute an intelligent AGENT. To enable a being to act with intelligence, two other faculties are requisite, viz., a Will to act, and a Power to execute or accomplish the act the being wills. This necessary co-existence of three distinct faculties in every intelligent agent seems to have been recognized from the earliest times, though no one, as far as we know, has distinctly stated this point, or noticed its important consequences, *totidem verbis*. The nature and relation of the three fundamental faculties, of knowledge, will, and power, to each other, are so interesting and wonderful, that it would occupy a volume to consider them in detail. The inquiry, however, is foreign to our present subject, and we shall merely offer a few illustrations.

A being may be supposed to exist, possessed of every kind of knowledge, but without the will or the power to act. Such a being may be an intelligent being, but can never become an intelligent agent. Moreover, it is not improbable that such intelligent but passive beings do exist. On the other hand, we can scarcely conceive an intelligent being to exist possessing the knowledge and the will but not the power of acting. An intelligent agent may indeed exist possessed of knowledge, and of will, together with a limited power of acting; and such limited intelligent agents are most of the subordinate agents we are actually acquainted with; not even excepting man himself; whose power of acting is far inferior to his knowledge and will. Did man possess the power, as he does the knowledge and the will, to act, what could he not accomplish? But, fettered by the gross elements of which his body is composed, while his knowledge and his will soar to other worlds, the actual power of man is limited to the bare superficies of this, the earth he inhabits.

Again a being possessed of knowledge and power, but without the will to act, cannot be supposed to become an intelligent agent; as the power, without the will to exert such power, would necessarily remain dormant, and never be called forth except by accident. There is, however, one remarkable peculiarity with respect to this latter supposition which we may briefly notice. We cannot conceive the possession of knowledge and of will by a being imparting to that being the power to act; neither can we conceive the possession of a will to act, and of the power to act, imparting to a being the knowledge how to act; but we can conceive the possession by a being of knowledge and of power calling forth, or producing the will to act. Hence in all intelligent agents the will perhaps may be viewed as the result, or offspring of the knowledge and power; and within the limits of the knowledge and power the will may be considered as free.

Lastly, if we abstract knowledge, and endeavour to imagine a being to exist possessed of will and power, or of power alone, we shall find the conception impossible. For on the principles above stated, a being can be supposed to will only what he knows; and if he knows nothing, he can will nothing; and if he neither knows nor wills, he never can become an intelligent agent, whatever may be his power,—a remark that naturally leads us to revert to the subject of physical forces; which may be defined to be unintelligent agents exerting power, without possessing knowledge or will. But physical forces act or are exerted according to a law. Now a law necessarily implies the existence of an intelligent Lawgiver, whose power is practically exerted when His law is carried into execution. Physical forces, therefore, in all their forms, may, as we formerly stated, be viewed as the delegated agents of a superior and intelligent Being; in other words, the mechanical forces displayed in the world around us, must represent nothing more nor less than the immediate and manifested power of the Deity.

Thus to recapitulate what has been said,—all intelligent agents must possess the three faculties of knowledge, will, and power, to enable them to accomplish any specific purpose. Of these three faculties, the will and the power are in such

intelligent agents limited by, or never can surpass, their knowledge; while in subordinate intelligent agents the power is usually far inferior to the knowledge and the will.

In one intelligent agent only are the three faculties of knowledge, will and power, commensurate and infinite; and from this infinite and everlasting Triune—The Great First Cause, spring all knowledge and all power; whether as possessed by created subordinate intelligent agents, within whose limited knowledge and power He has left the will free; or whether viewed simply as knowledge and power displayed by Himself through the medium of physical forces, acting in obedience to His will, according to certain fixed laws.

After these general remarks on the nature and qualifications of intelligent agents; the intelligent agents presiding in organized beings, and directing their operations, particularly claim our notice.

That the elaborate contrivances displayed in the structure of organised beings, are the result of intelligence, no one doubts. That this intelligence is primarily derived from the Great First Cause and source of all intelligence, no one, we presume, will deny. The question then is, in what agencies is this intelligence immediately vested? Is intelligence, as some contend, so vested in matter itself, as to enable matter to wield at will its own forces? Or, as others contend, have new forces been imparted to the matter entering into organised beings? Or, finally, as we contend, do there exist in organised beings, subordinate intelligent agents, belonging to a higher order of existences than the physical forces of matter, and possessing a certain limited faculty of wielding such physical forces at will? The consideration of these questions in detail belongs to a future part of this volume, where they will be shortly noticed. In the mean time, we shall close the present chapter with a recapitulation, partly supplementary to the leading points discussed in the foregoing pages.

Although matter and physical agency be in their intimate nature absolutely unknown; yet the phenomena they present, and their mutual relations, are to a certain extent cognizable, and lead us to the following conclusions:

1. Masses of matter exist and move in what we call space and time. But whether we view space and time as unities,

or as made up of many separate parts, we can neither assign limits to the unities, nor to the number of parts: that is, we cannot conceive a space, than which none can be greater or less; nor a number than which none can be greater or smaller. Were all the matter in the universe, therefore, collected into one mass, and that mass at rest, we should know nothing of space and time in the sense we now understand these terms; which is a relative sense only.

2. The positions of masses of matter in space, are constantly changing by the agency of two opposing forces, the one proper and attractive, the other resultant and repulsive. Neither the attractive force inherent in matter, nor the rotatory motion from which we suppose its repulsive force to result, can be proved to be necessary properties of matter; they are properties voluntarily superadded to matter by the Diety, when he called the present order of things into existence.

3. Matter by the agency of the two opposing forces so superadded, has moved, and will continue to move, throughout all time, according to certain laws, prescribed by the Deity, when He first put matter in motion; these laws the Deity himself never infringes, and they cannot, therefore, be infringed by any subordinate agent.

4. But although the forces exerted by matter, and the laws which these forces obey, can neither be suspended nor infringed; an intelligent being who understands the laws regulating these forces, and who possesses the will and capacity to direct them, by the aid of appropriate contrivances, may so influence their operation as to cause them to act in unusual modes, and thereby to produce unusual effects.

5. Lastly. There exist innumerable intelligent agents who, by the aid of appropriate contrivances are constantly combining matter into aggregates, which in virtue of its own physical forces alone, matter circumstanced as it is, would never form. Such aggregates are all organised beings; from the lowest animated corpuscle up to man himself.

CH. VI.—OF THE MUTUAL RELATIONS AND LAWS OF OPERATION OF THE FORCES OF GRAVITATION.

THE forces of gravitation, as we have stated, are attraction and *inertia*. These forces, and their laws of operation, may be thus illustrated.

In the first place, to form a notion of what is termed the *inertia* or inactivity of matter; let us imagine a portion of matter, as, for example, a ball of lead A, detached from all other matter, and existing absolutely uninfluenced in space. Such a mass of matter, if supposed to be at rest, must obviously remain so, for it cannot move itself. On the other hand, if the mass be supposed to be in motion, it must continue moving; for it cannot be conceived capable of stopping itself, any more than of setting itself in motion; in short, a mass of matter under such circumstances of isolation must be considered as perfectly passive and unable to change its condition, whatever that condition may happen to be, whether of motion or of rest.

Now let us suppose another portion of matter, as, for example, another ball of lead B, exactly of the same size as A, placed in free space at any moderate distance from A, and away from all other influences; what will happen? General experience teaches us, that under these circumstances, the two balls will mutually approach each other with an equal, but accelerated motion, till they meet at a point, exactly intermediate to the points at which they were when they first started; and the inference from this experience is, that the two balls exert a mutual and equal attractive force, which causes them to move toward each other. If the ball B be twice the size of the ball A, the two balls will mutually approach each other as before: but, in this instance, instead of moving with equal velocity; while the ball A, moves two feet, the ball B, will only move one foot; or taking an extreme case, and supposing the ball B, to be indefinitely larger, say a million times larger, than the ball A, they will mutually influence and mutually move towards each other as before; but the motion of the ball B, will be so minute as to be insensible, while the motion of the ball A, will be the greatest possible.

Here we have instances of the *inertia*, (inactivity, opposing force, &c.) and of the activity, (force of attraction, force of gravitation, &c.) which all matter was formerly stated to reciprocally exert toward all other matter: the laws of these forces, and the laws of the motions connected with them, as deducible from the circumstances above stated, or from other circumstances which it would be foreign to our present purpose to enter upon, may, in general terms, be expressed as follows:

"The mutual attraction of two bodies increases, in the same proportion as their masses are increased, and as the square of their distance is decreased; and also, the mutual attraction decreases, in proportion as the masses of the bodies are decreased, and as the square of their distance is increased."

These laws are absolutely general; and not only extend to the utmost limits of the universe hitherto explored by man; but to every form and condition of matter, without exception, and without reference to its other properties. These laws, therefore, constitute, probably, the most comprehensive "limits which the Deity has been pleased to prescribe to His power," and within which He operates with the most unceasing and undeviating regularity and certainty. These laws have also the remarkable property of being so amenable to the laws of quantity, or mathematics, as to be in most instances as firmly established upon reason, as abstract truths themselves. The mind of a Newton was chosen to reveal these laws to man; and man's acquaintance with them, may be justly considered as one of his noblest privileges. To point out their wonders in detail, and the sublime conclusions to which they lead, is the business of a colleague; at present we have to consider these laws in their more general form alone, and, except in a single application of them, merely as objects of comparison with the laws of molecular action more immediately connected with our own subject.

The application of the law to which we allude, is that peculiar case, or instance of gravitating force, termed weight. In our illustration of the attractive forces of matter above given, we supposed a case in which one ball was very much larger than another; now this precisely corresponds with the globe of the earth, and of all common bodies near

its surface. The Earth is more than 1,000,000,000,000,000 times the mass of any body which is observed to fall on its surface: and therefore, if even the largest body which can come under observation were to fall through a height of 500 feet, the corresponding motion of the earth would be through a space less than the 1-1,000,000,000,000,000th part of 500 feet, which is less than the 1-1,000,000,000,000th part of an inch, and therefore quite inappreciable.* Now the attractive force exerted between the Earth and detached bodies, is denominated Weight. Hence the weight of a body, at the earth's surface, is proportionate to its mass, or to the quantity of matter it may contain, whatever the form or qualities of that matter may be—a most important fact for the chemist; who, by employing the chemical properties of bodies as indications of identity or of change, is by these means enabled to apply to them the more certain measure of weight; and thus in some degree, to bring them under the dominion of the laws of quantity.

CH. VII.—OF THE MUTUAL RELATIONS AND LAWS OF OPERATION OF THE MOLECULAR FORCES OF MATTER.

In a former chapter we attempted to show that all molecular operations depend on the exertion of mutually opposing forces. Now as we know nothing of force in the abstract, or as independent of matter, it follows that matter is the common substratum or medium of all molecular operations: in other words, the phenomena of heat and of light; of electricity and of magnetism; of cohesion and of chemistry; are alike the result of forces mutually exerted by material molecules. Admitting this view, the molecules of matter concerned in the phenomena of heat and light, and of electricity and magnetism, must be of extreme tenuity, as no amount of them, hitherto accumulated, has been shown to have weight. The molecules of matter therefore concerned in the phenomena of heat and light, and of electricity and magnetism, have been termed Imponderable

* Cabinet Cyclopædia, Art. Mechanics, p. 79.

Molecules. On the other hand, accumulations of the molecules concerned in the phenomena of cohesion and chemistry, sensibly gravitate toward the earth, *i. e.* have weight; and hence the epithet of Ponderable Molecules, by which they are usually distinguished. This arbitrary division of material molecules into imponderable and ponderable is so convenient, that we shall provisionally adopt it; though, as before stated, we consider the opinion more probable, that all molecular operations are governed by the same laws, without reference to the weight or magnitude of the molecules.

With regard to the general relations of imponderable and ponderable matter it may be remarked; that the great intensity of the centrifugal forces exerted by imponderable, as compared with ponderable molecules, imparts to imponderable matters many of the characters of subordinate agents. In this character of subordinate agents, we shall have abundant occasion to consider heat and light, electricity and magnetism, in the next Book; when we come to speak of Meteorological phenomena.

Lastly, it may be observed that in no instance are we cognizant of the forces mutually exerted by a single pair of molecules. It is to be constantly borne in mind, therefore, that molecular forces, as we know them, are the general results of numerous molecules in simultaneous action. Thus the phenomena of heat and light, as they appear to us, are the joint results of myriads of molecules (or *undulæ*); and the action of a single pair of molecules (or *undulæ*) even if it produced the sensations we term heat and light, would be so transient, that its effects would probably elude our observation. Again, in the processes of cohesion and chemistry, we are only cognizant of the general phenomena produced by the numerous molecules of which the masses of matter we combine or separate, consist. Of the nature of the individual molecules composing such masses of matter; or of the changes or movements they undergo during these combinations and separations, we know absolutely nothing.

The subject of Imponderable molecules will occupy the present chapter, of which Section I. will include the pheno-

mena of Heat and of Light; and SECTION II. the phenomena of Electricity and Magnetism. The subject of Ponderable molecules will occupy the two subsequent chapters; viz. CHAPTER VIII. which will include the phenomena of Homogeneity or cohesion; CHAPTER IX. the phenomena of Heterogeneity or Chemistry.

§ 1.—*Of Heat and Light.*

Heat and light are so intimately associated in nature, and exhibit so many phenomena in common, that we shall consider them together.

The sensations termed heat and cold, light and darkness, are too well understood to require explanation. These sensations, however, like all others, are merely the effects of external causes, operating on and through our organs in a manner totally unknown to us. On the general nature of the causes producing these sensations we have already sufficiently spoken: and shall not therefore enter further on that part of the subject here.

As our sensations are very imperfect measures of temperature and of light; when we wish to speak with precision on these subjects, it becomes necessary to have recourse to other means of comparison. Hence, in the consideration of heat and light, the first point which claims our attention, is the mode of estimating their degree; and for the sake of the general reader, we shall premise the principles of the construction of the Thermometer and Photometer; the instruments for measuring heat and light.

Of the Thermometer.—All bodies, as we shall presently have occasion to explain, become more or less expanded in bulk, when they undergo an increase of temperature. Hence the relative degrees of expansion of any body may be viewed as a sort of measure of the degree of heat; and most of the thermometers employed, act on this principle. Thus the common thermometer, as is well known, consists of a portion of some fluid, generally of mercury, enclosed in a small glass ball, the cavity of which ball communicates with a tube of narrow bore. We shall suppose the quantity of the mercury, and the size of the ball, to be so adjusted to each other, that when the instrument is placed in ice on the one

hand, and in boiling water on the other, the whole expansion of the mercury, between these two fixed temperatures, shall take place within the range of the tube. The points at which the mercury stands in the tube, at the freezing and boiling temperatures, are to be accurately noted; and the intermediate space on the scale attached to the tube is to be divided into 180 equal parts or degrees; the freezing point of water is to be marked 32°; and of course the boiling point of water 180° above, or 212°. Such is Fahrenheit's scale, employed in this country; and to that scale the numbers hereafter mentioned refer. In foreign countries different scales are made use of: in Sweden, France, and elsewhere, what is termed the Centigrade thermometer is generally adopted. In this thermometer the freezing point of water is marked 0°, and the boiling point 100°. In other parts of the Continent, Reaumur's scale is much used. In Reaumur's scale the freezing point of water, as in the centigrade, is 0°; but the boiling point is only 80°. These different graduations are easily convertible, but it is to be regretted that they exist; as they cause much trouble and confusion.

Of the Photometer.—The instrument for measuring the relative intensity of light is termed a photometer. Of such an instrument various forms have been proposed; but at present they are all so imperfect; and, as compared with the thermometer, so little used; that we do not think it necessary to enter into details respecting their construction.

Heat, and perhaps light, exists in two distinct states: viz. in the sensible or moving state; or as heat and light in the ordinary signification of these terms; *i. e.* in motion, and appreciable by our organs; and in the insensible, latent, or statical condition. At present we shall confine our attention to the phenomena of sensible or moving heat and light. The subject of insensible, latent, or statical heat will be more advantageously considered when we come to speak of the natural conditions of bodies; and of the changes they are continually undergoing.

Of Heat and Light in motion.—Heat and light have a constant tendency to acquire a state of equilibrium; to which remarkable property their incessant motion, and interchange

among natural bodies, are chiefly to be referred. The motions of heat and of light, in one respect, viz. through the air and transparent media, are similar: light, like heat, does not move through opaque media; in two other respects, however, the motion of heat is peculiar. A common fireplace very well illustrates the whole of these motions of heat and of light.

If we place a thermometer directly before a fire, the thermometer will not only soon begin to denote an increase of temperature, but it will also be illuminated by the fire. In this case the heat and light have made their way through the space between the fire and the thermometer, by the process termed Radiation; a form of motion therefore common to heat and light. If we place a second thermometer in contact with any part of the grate, and away from the direct influence of the fire; we shall find that this thermometer will denote an increase of temperature, but not of illumination. In this case, the heat must have travelled through the opaque metal of the grate by what is termed Conduction; a form of motion consequently peculiar to heat. Lastly, a third thermometer, placed in the dark chimney, away from the direct influence of the fire, will also indicate a considerable increase of temperature; but not of light. In this case a portion of the air passing through and near the fire, has become heated, and has carried up the chimney the temperature acquired from the fire. There is, at present, no single term, in our language, employed to denote this third mode of the propagation of heat; but we venture to propose the term Convection;* which not only expresses the leading fact, but also accords very well with the two other terms. Motion by convection, like the motion by conduction, is peculiar to heat. From these facts it appears, that of the three modes by which heat may be propagated from one body to another, there is only one mode common to heat and light; and light, unlike heat, can neither be propagated through solid opaque bodies by conduction; nor be transported from one place to another by convection. In speaking of the principal phenomena connected with these motions of heat and of light, we shall reverse the order above given, and first consider the

* *Convectio,* a carrying or conveying.

Phenomena of the conduction and convection of heat.—The conduction of heat is chiefly confined to solid bodies; and as solids exist in every degree of consistency and density, from perfect fluidity up to perfect hardness; the conducting power varies in like manner. The conduction of heat through bodies seems to take place equally in all directions. In general, the densest bodies, as metal, stones, hard woods, &c., have the greatest conducting power; though these bodies differ exceedingly from one another. Porous bodies, in general, are bad conductors; and of such bodies, charcoal may be considered as one of the worst. Among substances employed as articles of dress, hare's fur, and eider down, are the worst conductors, and flax the best. The relative conducting powers of this class seem to depend much on the quantity of air enclosed within their interstices, and on the power of attraction by which this air is retained or confined.

The conducting power of liquids and of gases is very limited, though under certain circumstances they appear to possess this power in a high degree. But in liquids and gases the conducting power is only apparent; and heat is principally communicated through liquids and through gases by the third process above alluded to, viz., convection. By convection, however, heat is chiefly propagated in one direction, that is to say, upwards. Hence almost any degree of heat may, for a time, be applied to the upper surface of a liquid or of a gas, without materially affecting the temperature of the lower surface.

Such are the principal phenomena connected with the conduction and convection of heat: and among the operations of nature these phenomena are of constant occurrence, and will be found to be of the utmost importance.*

Of the Radiation of Heat and of Light.—Heat and light radiate in all directions in straight lines and with inconceivable velocity. Heat and light, when of considerable intensity, appear to radiate nearly alike through all gaseous bodies, and other transparent media. The passage of heat and light, though transparent media, is much influenced, however, by their degree of intensity, as well as by the thickness of the transparent media, and by other circum-

* See Appendix.

stances at present imperfectly understood. Thus the low heat from boiling water readily passes through a thick plate of rock salt, but is effectually stopped by a very thin plate of glass; while light of every degree of intensity, as far as is known, passes equally well through both media.

Radiant heat and light are reflected from the surface of bodies according to the same mechanical laws to be presently noticed; but the degree of their reflection, as well as of their absorption by the surfaces of bodies, depends much on the nature of the surface, &c. In a great many instances those surfaces which reflect light most perfectly, are not equally adapted to the reflection of heat. Metals, for example, particularly when highly polished, are the best reflectors of heat; while glass, a most perfect reflector of light, reflects comparatively little heat. Thus tin plate reflects about eight times as much heat as a glass mirror.

The radiation likewise of heat and of light from bodies, varies according to the nature and state of their surface. Thus a surface coated with lamp-black, by which little or no light is radiated, radiates eight or nine times as much heat as a polished surface of tin or of silver; and, in general, polished sufaces, particularly of metal, radiate much less than other surfaces. As might be expected, difference of radiating power exerts great influence in the cooling of bodies; thus warm water retains its heat much longer in a bright tin vessel, than in the same vessel coated with linen, paint, or particularly lamp-black.

Radiant heat and light are absorbed with different facilities by different surfaces. The absorbing power of surfaces, as regards heat in particular, seems to vary directly as their radiating power, and inversely as their reflecting power. That is, surfaces receive heat by radiation, nearly with the same degree of facility as they give it off: while those surfaces which reflect most heat, (and we may add light,) of course must absorb least heat: a surface covered with lamp-black, for example, receives, in a given time, eight or nine times as much heat by radiation, as a polished tin surface receives. From these statements it will be readily inferred that the colours of bodies may have considerable influence on the radiation and absorption of heat

and light. Now such is found to be the case; and the darker the colour of a body, the more readily it absorbs heat and light, and gives off radiant heat. These properties of radiant heat and light are all of the greatest importance in the economy of nature, and will be often referred to hereafter.

Of the Mechanical Laws of Heat and Light in motion. The laws of the motion of heat and light, *i. e.* of their Reflection, Refraction, Polarization, &c., properly belong to another department; we shall therefore treat of these laws briefly, and as far only as they illustrate our subject in general. As the longest known, and therefore the most familiar, we have chiefly confined our illustration to the phenomena of light in motion, and shall only remark that the same laws of motion, with some differences not requiring explanation here, are found to apply to heat in motion.*

Reflection and Refraction of Light.—In free space, as before observed, light moves in straight lines: but when a ray, R, Fig. 1, falls upon a polished surface, as of glass, a

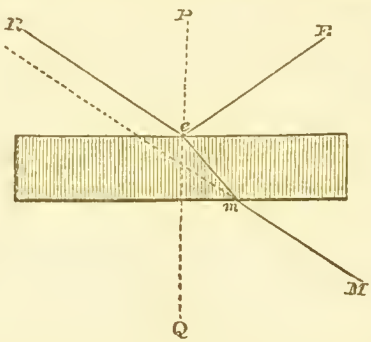


Fig. 1.

portion of the light is reflected in the direction *e* E, and the angle, R *e* P, called the angle of incidence, is always equal to the angle, P *e* E, called the angle of reflection. Another portion, *em*, passes through the glass; but instead of continuing to move in the same straight line, is bent considerably out of that direction, toward the perpendicular P Q;

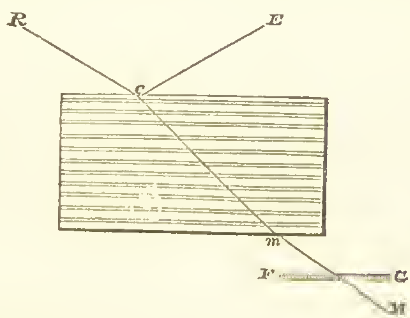
* The reader who is interested in the polarization of heat, in particular, is referred to an Essay by Professor Forbes of Edinburgh, by whom the phenomena were first clearly illustrated.

the bent portion of the ray then makes its exit at *m*, and goes on in the direction of *m* M, parallel to its original direction, R *e*. This portion of the ray is said to have undergone refraction; a term indicating that its natural course has been broken. Such are the general facts: the study of their laws, varieties, and peculiarities, as modified by different media, constitutes the science of optics; a branch of knowledge not falling within our present inquiry. In connection with this part of our subject it only remains to observe, that in passing through the most transparent bodies, much light is lost by absorption, and in other ways. So also when light falls upon metallic bodies, such as polished silver, about one-half only is reflected; while the other half is aborbed and lost. Different substances, however, differ materially in these respects: thus, from the experiments of M. Bouguer and M. Lambert, it appears, that in fluids, transparent solids, and metals, the quantity of light reflected, increases with the angle of incidence, reckoned from the perpendicular; whereas in white opaque bodies, the quantity of light reflected, decreases with the angle of incidence.* We shall hereafter have occasion to revert to these curious facts.

The reflection and the refraction of heat, though subject to differences formerly alluded to, appear to follow the same general laws as the reflection and refraction of light.

Polarization of Light.—The next property we have to notice is what is called the polarization of light. Let us

Fig. 2.

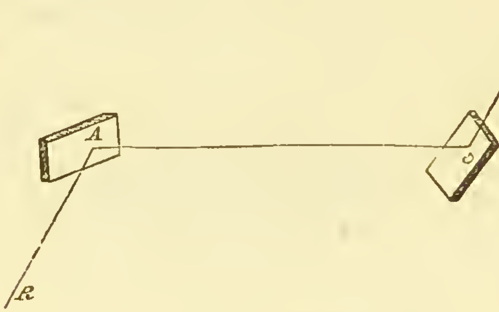


* See article Optics, p. 67 and 68, in the Library of Useful Knowledge. Where the original observations are to be found, which are there referred to, we do not at present know.

suppose Fig. 2, to represent a bundle of plates of thin window-glass, bound together in the manner indicated. Let R *e* be a ray of light falling on the upper plate at an angle of incidence of about 56°: a portion of the ray will be reflected, and will move in the direction *e* E; while another portion of the ray, *e m*, will pass through the bundle of glass plates onward to M; according to the laws of reflection and refraction already stated. Now these rays *e* E, and *m* M, possess remarkable properties; similar to one another in most respects; but directly opposed in another. Of these properties we shall endeavour to give a general idea.

If, after the ray of light R A, has fallen upon the vertical glass A, Fig. 3, at an angle of incidence of 56°; the reflected portion of that ray, A C, be received on a plate of glass, C, placed at the same angle of incidence; and if this reflected portion of the ray be again reflected from C to E, in the position intended to be shown in the figure;

Fig. 3.



when the ray R is first reflected in a horizontal plane, R A C, and then in a vertical plane, A C E; the portion C E, which remains of the original ray after this second reflection, becomes so weak as to be scarcely visible; the whole of A C, the first reflected portion of the original ray, having passed through the glass C. But if the glass C be turned round 90°, (the first reflected portion of the ray A C, being supposed to be the axis of motion,) so that the second reflected portion, C E, be reflected horizontally; instead of A C passing through the glass C, as before, the whole of A C will be reflected a second time in C E. By

continuing to turn the plate C upon the axis A C, round the entire circle; these alternations of transmission and reflection, will be found to take place in the same manner, at the two other quadrants 180° and 270°. Hence the ray R A, by reflection, has acquired properties altogether new; it is said in short, to have acquired polarity, or to have become polarized. Now recurring to Fig. 2, the ray R *e*, in that figure, will of course obey the same laws as the ray R A, in Fig. 3; that is to say, the ray *e* E will have acquired polarity by reflection. Let us now consider what has happened to the refracted ray *m* M, in the same Fig. 2. This ray *m* M will also be found to be polarized; but if we receive it on a glass plate, F G, at the polarizing angle of 56°, we shall find that it will refuse to be reflected; whereas the reflected ray *e* E does not refuse to be again reflected, unless the plate F G be turned round 90°; or be turned round into a plane at right angles to that plane in which the refracted ray *m* M, had refused to be reflected. Hence we conclude, that when a ray of light is incident at the polarizing angle, upon a transparent body, the whole of the reflected light is polarized, while the whole of the transmitted light is also polarized—but in a plane at right angles to that in which the reflected ray is polarized.

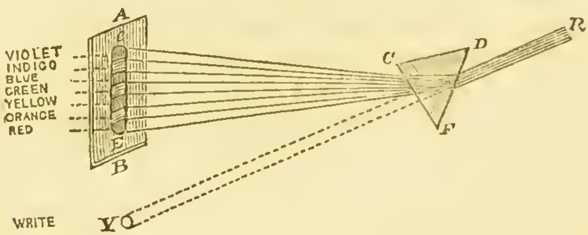
Such is the general law; and it may not be amiss to allude briefly to another familiar illustration of it. Every one is acquainted with the mineral called Iceland spar, and with the singular property which this mineral possesses of forming a double image of objects seen through it, or its property of double refraction; in other words, when a ray of light falls on a crystal of such spar in a particular direction, the ray is separated into two. Now it is a remarkable fact that if these two rays be examined in the way before directed, when speaking of reflected and transmitted light; it will be found that both rays are polarized, but that the two rays are polarized in planes at right angles to each other: that is to say, the ordinary transmitted ray is polarized like the ordinary ray transmitted through the bundle of glass plates; while the extraordinary transmitted ray is polarized like the ray reflected from these plates. Many bodies are similarly constituted; while others have two or more planes or axes of double

refraction, giving origin to a variety of curious and beautiful properties, which it would be quite foreign to our present purpose to detail further.

The *Polarization of Heat*, as we have already stated, obeys the same general laws as the polarization of light. (See note p. 46.)

Decomposition of Light.—When a ray of light from the sun R, Fig. 4, traverses a prism, C D F, instead of passing

Fig. 4.



onward in the direction Y, it is refracted into the spectrum E *e;* which spectrum when received upon the screen A B, will be found to consist of seven different colours, in the order represented in the figure, each having, of course, different refractive powers; the red being the least, and the violet the most, refracted from R Y, the original direction of the solar beam. This oblong image is called the solar, or sometimes, the prismatic, spectrum; and Sir Isaac Newton found that each colour consists of light no longer separable into others, like white light, but having uniform refractive properties: hence he called all these seven colours simple, or homogeneous; in opposition to white light which he called compound, or heterogeneous.* The composition of light, presents a clue to, and exhibits the general law which regulates, the endless variety and change of colours:

* Sir David Brewster has lately shown that there are, in fact, but three simple colours, the red, the yellow, and the blue; and that all these three colours exist throughout the spectrum. (The most recent experiments and inductions are, however, opposed to this view; and in favour of the existence of numerous, probably an infinite number of primary rays or colours. See the Memoir of Helmholtz, in the Philosophical Magazine for 1852, vol. 4, p. 401; the works there referred to; and Pereira's Lectures on Polarized Light, by the Rev. Baden Powell, p. 25.)—G.

since bodies appear to have this or that colour, according as they have the power of reflecting or transmitting the rays of this or that colour, and of absorbing or reflecting the rest; while white bodies reflect all the rays, and black absorb all.

Besides colour, it has been likewise noticed, that different portions of the prismatic spectrum possess different heating, and chemical or electrical, properties. These properties vary in some respects, according to the nature of the prism employed. In general, the heating power increases toward the red ray; while the chemical power increases toward the violet ray: the chemical power, however, (which seems to be regulated in some degree by the nature of the colour,) is said to be of an opposite character to the heating ray, and greater at the extremities of the spectrum than in its centre.

The chemical properties of light, or of some influence propagated from the sun along with light, have lately attracted much attention. The facts elicited are exceedingly interesting, and have been practically applied to various purposes, particularly to the taking of likenesses. The influence of the chemical properties of light in the economy of nature is as yet but little understood; though it is probable that their effect is very great in many natural phenomena.

Of the Sources of Heat and Light.—The principal and obvious sources of heat and light are the sun, electricity, mechanical action; change of physical condition, change of chemical condition; and organic action. For the sake of convenience, all these sources of heat and light may here be briefly noticed together.

The sun is the great and unvarying source, from which both heat and light are communicated to our earth: but the nature of the sun, and the mode in which that wonderful supply of heat and light is maintained, are quite unknown to us, and will probably always remain so. Electricity is another source of heat and light, which are developed at the moment of the equilibrium of the two energies; and some of the most intense degrees of heat and light that have been produced, have sprung from a galvanic apparatus. Heat and light are also a frequent

result of the sudden condensation of air; on principles, not perhaps difficult to be understood from what has been already stated. The heat arising from the percussion and condensation of solid bodies appears to be limited, but its extrication by friction seems to be boundless: that is to say, so long as friction is kept up, heat will continue to be evolved; but whence the heat is derived, does not appear to be capable of satisfactory explanation. Another fertile source of heat is the physical change of condition which bodies are constantly undergoing in nature: such as the conversion of gases into liquids; of liquids into solids; &c. By taking advantage of these conversions, we can accumulate heat at will; as for instance, by the condensation of steam. The most striking effects however are produced when such physical changes are associated with chemical changes, as is very often the case. Physical and chemical changes are so associated in combustion, the most common source of artificial heat: where all the phenomena consist of nothing more than the rapid chemical union of certain bodies with others; and generally, with the principle termed oxygen. Nearly allied to chemical action, and perhaps identical with it, is the disengagement of heat by organic changes, or what is termed animal heat; a subject we shall have to consider in a future part of this volume.

In concluding, for the present, our remarks on heat and light, it only remains to observe, that the phenomena, and laws of motion, of these subordinate agents, are all of the highest interest; as constituting limitations and principles of action, to which the Great Author of nature most rigidly adheres in His operations. Hence, whether we view the distribution of heat and of light on the large scale, as regulating climate; or whether we view heat and light with reference to the most trifling particular, as the clothing of a bud or of an insect: we find the same beautiful adaptation and contrivance, every where exemplified, to ensure, or to evade, the agency of these all-important principles. The wonderful arrangements connected with heat and light, will, however, fall more naturally to be considered in another part of this volume: we shall therefore defer what we have further to say regarding them till we come to Meteorology.

§ 2.—*Of Electricity and Magnetism.*

The agencies of electricity and magnetism and their power in the economy of nature, were entirely unknown till recent times. The ancients, indeed, had observed that amber when rubbed, acquired the property of attracting straws and other light bodies, in the same way they had observed that the magnet attracts iron; but they carried their enquiries no further; and the names Electricity and Magnetism comprise all we have received from the ancients relative to these subjects.*

Without entering into details for which we must refer the reader as before to works expressly written on these two branches of knowledge, we shall give a brief outline of the leading facts connected with them.

Of Electricity.

There are two modifications of Electricity, viz., Electricity properly so called; and what is termed Galvanism or Voltaic electricity. These two modifications of electricity, as will be afterwards explained, arise from differences in the mode and degree of operation of the same energies; the phenomena however are so dissimilar that they are usually considered under the two separate heads of *a.* Electricity, and *b.* Galvanism, which arrangement accordingly we shall adopt.

a. Of Electricity.—When certain substances, as amber above-mentioned, also sealing wax, glass, &c., are rubbed with a dry silk cloth, they acquire the property of attracting or of being attracted by contiguous bodies lighter or heavier than themselves. Bodies that have acquired these properties are said to be electrified, or to be electrically excited; and the force which causes the action between electrified and other bodies is termed electric attraction. But this electric attraction is not the only force developed. It will be found

* The term electricity is derived from ἤλεκτρον, the Greek word for amber. Magnetism also is of Greek origin, being immediately derived from Μάγνης, a magnet. It is probable, however, that both these terms are of an origin anterior or foreign to the Greek language.

that light bodies after they have touched an electrified substance, recede from it, just as actively as they approached it before contact. This opposite force is termed electric repulsion. By the aid of the common electrical machine these phenomena of electric attraction and repulsion may be displayed in a great variety of amusing as well as instructive forms.

At the very outset of electrical discovery, the remarkable fact was noticed that certain bodies only are capable of becoming electric by friction. This observation naturally led to the division of substances into electrics and non-electrics. It was soon found, however, that in reality all bodies are by friction electrically excited alike; but that while the electric energies, as fast as they are excited in some bodies, escape along their surface or through their substance, these energies are retained by other bodies; and consequently that to accumulate electricity in non-electrics, it was merely requisite to insulate or surround them with electrics. Those bodies from which the electric energies readily escape are now called conductors, while those bodies by which they are retained are called non-conductors, of electricity. The principal conductors of electricity are the metals, charcoal, and water; the principal non-conductors are glass, resins, sulphur, dry wood, and among organized bodies, silk, hair, and wool. Air and gases in general when dry are non-conductors of electricity, but act as conductors when saturated with water. A knowledge of the conducting and non-conducting properties of bodies is of the utmost practical value, as on these properties depend almost all the phenomena of electricity, whether naturally or artificially produced.

Another early electrical observation, was the not less striking fact that the electric energies manifested by glass and sealing wax, when rubbed by the same woollen or silk cloth are essentially different. Hence it was inferred that there are two kinds of electricity, one then termed vitreous electricity, because developed on glass; the other resinous electricity, from being first noticed in resinous substances. Further investigation, however, into the nature of these phenomena, as in the case of the terms electric and non-electric before mentioned, led to a change of nomenclature;

and the terms positive and negative electricity, are now adopted for vitreous and resinous electricity. The mode of distinguishing between positive and negative electricity is founded on the circumstance, that if two electrified substances are both positive or both negative, they are invariably disposed to recede from each other,—that is, to exhibit electric repulsion; but if one be positive and the other negative, their mutual action is as constantly attractive.

Substances differ exceedingly with regard to their positive and negative electric relations. When almost any two substances are rubbed together, the one becomes positively, the other negatively excited; and very often the same substance will apparently possess both forms of electricity at the same time; that is, will appear positively electrified by friction with one body, and negatively electrified by friction with another.

The phenomena of electricity have been explained on different principles by different philosophers. It seems now however to be generally admitted, that these phenomena depend on two energies or forces usually existing throughout nature in a state of equilibrium, in which state their peculiar powers are not perceptible; that this equilibrium is capable of being destroyed by a variety of causes, as by friction, for instance, in the cases we have stated; and that owing to the different capacities possessed by different bodies for conducting and retaining the electric energies, these energies can be partially separated and kept asunder, in which state they are capable of exhibiting their peculiar powers. But in this disturbance of the equilibrium of the two electric energies, it is to be remarked that in no instance do we suppose that the two energies are, or can be entirely separated, so as to reside each *per se* in different bodies; but that a portion of the energy of the one body goes to the other body, which at the same time returns a corresponding portion of its antagonist energy: hence, other things being equal, each body contains the same total quantity of the two electricities as before the equilibrium was destroyed.

Of the Sources of Electricity.—The principal sources of electricity are the friction of bodies already noticed; also

change of temperature; chemical action; contact; changes of form; and proximity to an electrified body. To several of these sources of electricity we shall have occasion to recur in future parts of this volume. The electrical excitement produced by proximity to an electrified body, requires especially a brief explanation here, as being connected with a very interesting class of phenomena, termed the phenomena of induction.

Suppose an electrified body A, (that is, a body having the equilibrium of its electric energies destroyed in the manner before explained) be brought into the neighbourhood of another body B having its electrical equilibrium entire, what takes place? The electricity E of the body A, acting on the corresponding electricity E in the body B, repels this electricity E to the end of the body B which is farthest from the body A; at the same time, the other and opposite electricity *e*, is attracted to the end of the body B which is nearest to the body A. The body B therefore, while under the influence of the body A, will exhibit all the phenomena of electricity, and is said to be electrified by induction. But if the body A be removed from the neighbourhood of the body B; immediately the natural equilibrium of the energies of the body B will be restored and all signs of electricity will vanish. In this experiment neither of the bodies gains or loses anything. As such phenomena are constantly occurring in nature; and as we shall have occasion to use the word induction, we have endeavoured to give, as regards common electricity, an explanation of the phenomena intelligible to the general reader.

b. Of Galvanism, or Voltaic Electricity. The whole of this branch of knowledge, which owes its origin as well as its name to the Italian anatomist Galvani, may be said to have been developed within the last sixty years. To Volta, however, another Italian philosopher, the credit is undoubtedly due of placing the subject on a scientific basis; and hence the term voltaic electricity, adopted by some writers.

Common electricity and voltaic electricity arise from the same forces; but these forces are in general excited by different means, and operate in a different manner as well as under different circumstances. Common electricity, as

we have seen, is usually developed by the contact of dissimilar bodies in motion, as by friction, &c.; and when developed, the condition of the energics is usually statical or quiescent, and are only momentarily in motion. Voltaic electricity, on the contrary, is for the most part developed by the quiescent contact of dissimilar bodies; and when developed the energies are usually displayed dynamically or in constant motion.* This statement furnishes a clue to the leading distinctions between common and voltaic electricity, and if borne in mind will enable the reader to understand the few remarks we have to make on these subjects.

When two insulated plates of different metals, zinc and copper for instance, are brought into contact and again separated, the electrical equilibrium of both plates will be found to be destroyed. In the case supposed, the zinc will be found to have acquired an excess of positive electricity, and the copper an excess of negative electricity; that is of the common electricities described in the preceding section. But if the two plates of metal be immersed in water, or dilute acid, and then be brought into contact, either immediately, or mediately by means of a conducting wire, it will be found that as long as the two metals remain in contact there will be a constant current of positive electricity circulating from the zinc through the water or diluted acid to the copper; and from the copper, through the point of contact or connecting wire of the two metals to the zinc; and on the other hand, that a similar constant current of negative electricity will be traversing the circuit described, in an opposite direction, *i. e.* from the copper to the zinc, through the water or dilute acid, and from the zinc to the copper through the point of contact, or the wire connecting the two metals. Such are the elementary forms and relations of common electricity and of voltaic electricity. The combination above described constitutes what is called a simple voltaic circle; and such a voltaic circle may be formed

* Strictly speaking the phenomena of electricity and galvanism are both dynamical, and both are exerted during the motions of the same energies; but as stated in the text, the energies in the phenomena of electricity are only momentarily exerted, while in the phenomena of galvanism they are exerted continuously.

of very various materials; but the combinations usually employed consist either of two perfect and one imperfect conductors of electricity, or of one perfect or two imperfect conductors. The substances included under the title of perfect conductors, are metals and charcoal; and the imperfect conductors are water and aqueous solutions. It is to be observed, however, that metallic bodies are not essential to the production of galvanic phenomena. Combinations have been made with layers of charcoal and of blacklead; of slices of muscle and of brain, and of beet-root and of wood, &c.; but the forces developed by these circles, are very feeble compared with forces developed by the metals above stated. It is also to be observed that when the voltaic circle consists of two perfect and one imperfect conductors, the imperfect conductor acts chemically on one or both of the perfect conductors; while at the same time the imperfect conductor, water for instance, is decomposed, and one of its elements, oxygen (in the case of water,) is conveyed to the metal most acted on, (zinc in the case supposed,) and the other of its elements, hydrogen, is conveyed to the metal least acted on (copper): further that the metal most acted on (the zinc) is generally positive with respect to the metal least or not at all affected (the copper); and finally, that this inequality of chemical action on the two perfect conductors is essential to the operation of the voltaic circle.

Thermo-electricity.—The feeble currents of electricity developed in bodies, by inequality of temperature and compression differ in no respect, except in degree, from the common electric currents above described.

When a number of simple voltaic circles are so arranged as to act together at the same time, their joint intensity within certain limits increases with the number of circles employed. Such an arrangement is termed a compound voltaic circle, and constitutes, under various forms, the common voltaic or galvanic battery.

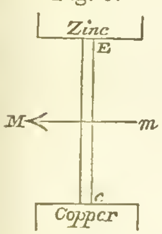
Of Magnetism.

The mechanical phenomena and laws of magnetic forces are very analogous to the mechanical phenomena and laws

of electric forces. There are evidently two antagonist magnetic forces or energies, which, while in a state of equilibrium, are not cognizable; but when separated, each of the two energies repels and is repelled by a similar energy, but attracts and is attracted by an opposite or antagonist energy. Thus the two north or two south poles of two magnetic needles mutually repel each other; while the north pole of one needle, and the south pole of another, mutually attract each other. Bodies capable of acquiring magnetism are also rendered magnetic by induction, when placed near another magnet, exactly as happens with respect to electricity. The chief difference of magnetism from electricity consists in magnetism being apparently limited to a few bodies; as iron, and two or three others. But late observations have thrown an entirely new light on this part of the subject; and we shall now proceed to consider it.

The relation of electricity and magnetism to one another is a discovery which we owe to Professor Oersted of Copenhagen, and is one of the most important that has been made in the present age. The following is a summary of Oersted's discovery.

Fig. 5.



Let us suppose, in the annexed fig. 5, E *e* to represent the wire connecting the zinc and the copper terminating plates of a compound voltaic circle, or common galvanic battery in action. From what has been said, it may be conceived that under these circumstances, there will be two currents moving through this wire in opposite directions; a current of negative electricity from the copper to the zinc, and a current of positive electricity from the zinc to the copper.* Now in this state of things, it has been satisfactorily established by experiment, that besides these two currents, there are two other currents having totally different properties, indeed all the properties of the magnetic energies, moving, not in the direction of the wire, but in circles or rather in spirals round the wire. The energy corresponding

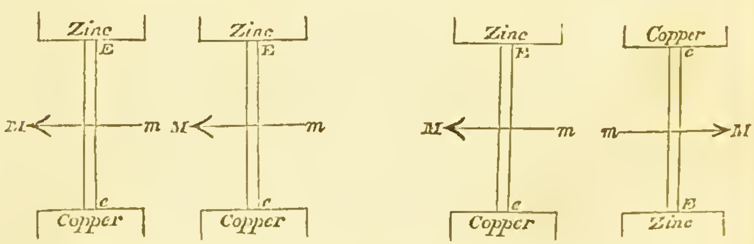
* The reader will observe, that the above observations apply to a wire connecting the terminating plates of a common galvanic battery; which plates are in reality superfluous. Hence the currents and polarities here given, are just the reverse of those which actually exist in a wire

with the north pole of the magnetic needle moves from right to left, round the wire as above posited; while the energy corresponding with the south pole of the magnet moves in the opposite direction, or from left to right. Hence when a delicate magnetic needle, M m, is suspended above the wire E e; its north pole M, will be attracted by the current moving from left to right, with which it comes first in contact: and its south pole, for similar reasons, will be attracted by the opposite current. A needle so suspended will consequently assume the direction represented in the figure, with its north pole M to the left: and if the needle, in a state of free suspension, be carried round the wire, it will be always found to keep the same relative position with respect to the wire. Thus when below the wire, the needle will apparently point in a direction opposite to that shown in the figure; when on the same level, on the left hand, the needle will point vertically downwards; when on the right, upwards.

Bearing in mind these relative positions of the currents and needles; in what follows we may neglect the currents. and judge from the position of the needles alone. Let us consider the case of two connecting wires placed by the side of each other, as in the figures annexed.

These wires, in consequence of the magnetic energies circulating round them, will mutually attract or repel each other, according to their position. If, as in Fig. 6, they

Fig. 6. Fig. 7.



are both in the same relative position, they will mutually attract each other; as may be inferred from the position of

connecting the zinc and copper in a simple galvanic circle, as above described. We have thought it proper to notice this circumstance, in order to prevent misconception.

the needles M *m*, M *m*, the north pole of one of which needles corresponds with the south pole of the other: but if one of the wires be reversed, as in Fig. 7, the needles will mutually repel each other, their two similar poles being in this case contiguous. These relations hold universally; and what is most curious, recent observations have shown them to be, under certain slight modifications, reciprocal; that is, if the magnetic energies be made to move in straight lines, the galvanic energies are found to circulate round them, nearly according to those laws above explained, as regulating the currents of the magnetic, round the electric, energies. Hence, by appropriate arrangements, electric sparks, and indeed all the phenomena of electricity, can be obtained from a common magnet.

Such are the singular phenomena and relations of electricity and magnetism; to which we shall have repeated occasion to refer when speaking of the influence of these wonderful agencies among the phenomena of nature.

In briefly recapitulating what has been stated, we shall endeavour to illustrate the subject a little further.

The reader will bear in mind that the phenomena of electricity are known to us only as phenomena of motion. Thus, however highly an electrical battery may be charged, still it presents nothing remarkable till the communication between the two surfaces is restored; at which instant the energies we term electric are developed in motion, through the connecting medium. Now in this case of the charged electrical battery, the two electric energies have been previously separated and accumulated on the opposite sides of the battery. They are ready therefore to assume their natural state of equilibrium as soon as a channel of communication presents itself; and this restoration of the equilibrium between the two energies, though complete and final, is the work of a moment only. The operation of the galvanic battery is quite different. Here there is little or no accumulation; but the electric energies pass through the connecting medium as fast as they are separated. The difference of operation arises from the difference of circumstances. In electricity the tension of the accumulated electric energies is great, but the time required for the restoration of their equilibrium is the least possible. In

galvanism, on the contrary, the tension of the electric energies from the absence of accumulation is small, but the restoration of their equilibrium is continuous.

There is another point of difference between electricity and galvanism intimately connected with the phenomena of their action, viz., the difference in the quantities of the two energies. In the largest electrical battery, the quantity of the electrical energies must be comparatively small, since their equilibrium is completely restored by a momentary communication through a small connecting medium; whereas the quantity of the electric energies developed by the continuous action of a galvanic battery must be comparatively very large. Indeed it has been stated that the quantity of the electric energies developed during the decomposition of a single grain of water, by a galvanic battery, is more than sufficient to form a powerful flash of lightning. In the common galvanic apparatus the quantity of the electric energies developed depends on the size of the plates; while their intensity, within certain limits, increases with the number of the plates. Hence the only effect produced by extending the number of plates in a galvanic battery, is to render galvanic electricity more nearly alike to common electricity.

Lastly, the motions of the electric and magnetic energies are so related, that while the electric energies, from whatever source derived, move in straight lines, the magnetic energies invariably circulate round the moving electric energies in the form of spirals; and these relative motions of the electric and magnetic forces are inseparably connected.

It remains to notice very briefly the different theories which have been advanced to explain the phenomena of electricity. The phenomena of galvanic electricity were ascribed by Volta to the simple contact or communication between the different metals or substances composing the apparatus. This opinion, however, was soon supplanted by the opinion, that the phenomena of galvanism are solely due to the common electricity developed during chemical action; and this seems to be the opinion at present entertained. That the quantity of the galvanic energies bears a constant relation to the quantity of chemical action, seems to be

established; but the admission of this fact does not prove that galvanic action and chemical action are the same, nor that the two actions are related to one another, as cause and effect. On the contrary, the circumstances connected with the fact, to us clearly appear to show, that galvanic action and chemical action are only different expressions for the same effect, resulting from the same pre-existent cause. When speaking of chemical action in a subsequent chapter, we shall have occasion to recur to this point.

Instruments for measuring the quantity of the electric energies developed are called Electrometers, Galvanometers, &c. Of these there are several. One of the most common consists of a magnetic needle appropriately arranged; which when placed in the electric current shows by its angular deflexion, the quantity of electricity in the current, without being affected by its intensity.*

CH. VIII.—OF HOMOGENEOUS ATTRACTION AND REPULSION: COMPRISING A SKETCH OF THE PHENOMENA DEPENDENT ON THE COHESIVE AND DIVELLENT FORCES MUTUALLY EXERTED BETWEEN MOLECULES OF THE SAME MATTER.

THE reader will bear in mind that homogeneous bodies may be subdivided into molecules, each one of which molecules, though retaining all the properties of the original body, is yet so minute as to elude our senses. Now the mutual relations and influences of the forces exerted by such minute and similar molecules constitute the phenomena of Homogeneity, or the Cohesion and Divulsion of similar matter.

The important subject of cohesion and divulsion cannot be better illustrated, than by a survey of the obvious and unvarying effects of the cohesive and divellent forces exerted

* We have retained the old explanations of intensity and quantity of electricity, as they are convenient for illustrating the phenomena; but it has been lately shown, that in all instances, the action of an electric current is equal to the sum of the electro-motive forces divided by the sum of the resistances; and that whatever be the nature of the current, if this quotient be equal, the effect is the same.

among molecules of the same matter, on which the constitution and forms of aggregation of natural bodies depend. We shall therefore briefly notice,—First, *a.* the constitution of bodies as they exist in their solid, liquid, and fluid forms of aggregation; and—Secondly, *b.* the changes with regard to their constitution which all homogeneous bodies are constantly undergoing in nature.

a. Of the constitution of natural bodies in their solid, liquid, and fluid forms of aggregation.

When treating of the divisibility of matter, and of natural bodies in their solid, liquid, and fluid forms, as contemplated by the natural philosopher, we gave some general details of their internal constitution. In considering, however, these different forms of matter with reference to cohesion and chemical action, it will be necessary to enter a little further into detail on other points. We shall therefore take a brief view of the leading facts connected with the constitution of bodies in their different forms of aggregation.

Of the solid form of matter. Natural bodies exhibit a variety of properties usually termed secondary, many of which properties are of the utmost value to mankind. Such are opacity and transparency, hardness and softness, elasticity, toughness, malleability, tenacity, ductility, density, &c., all too well understood to require definition here. These properties evidently depend in a great degree on original differences in the properties of the minute molecules of which we have shown all bodies to consist; but there is no doubt that many of these properties are intimately connected also with the modes in which these molecules are arranged or aggregated. Of these modes we can form no precise idea in a great many instances; there is, however, one form of solid aggregation, the regular crystalline form, which has occupied much more attention than the rest, and this form we shall endeavour to illustrate.

As an object of illustration we shall select, as before, the familiar one of water; which from its well known properties of existing either as a solid, a liquid, a vapour, or a gas, by a slight variation of circumstances, is well adapted for our purpose, because we are thus enabled to employ the same object of illustration throughout. In conformity with this view we have at present to consider water in its solid form of ice.

Every one must have observed that water, in the act of freezing, assumes various symmetrical figures, shooting into spicula, &c., as may be beautifully seen on our windows on a frosty morning. Now these icy spicula afford a familiar instance of what is termed crystallization; a property apparently possessed by all ponderable matter, and readily exhibited by such matter, when under favourable circumstances: and it has been remarked, that the figure assumed by the same matter is usually similar, or easily deducible from some common figure, according to well-ascertained and obvious laws. Let us now briefly inquire into the properties which the molecules of matter must be supposed to possess, to enable them to produce these symmetrical aggregations.

In the first place, it is evident, that the simple supposition of a mutually attractive force between these molecules, analogous to, or identical with, the attractive force of gravitation, is inadequate to explain the phenomena. Possessed of such an attractive force alone, the component molecules of bodies might indeed be imagined to adhere together, and their aggregations might even exhibit something like regularity; but this regularity would in a great measure be accidental, and probably never twice alike: hence the utmost latitude of assumption would never enable us to explain upon such principles alone, that sameness of figure above noticed, which is always assumed by the same matter. It is obvious, therefore, that the component molecules of bodies are influenced by other powers, than that of the simple attractive force of gravitation: what is the nature of these powers? On this point there have been various opinions. Some have supposed the component molecules of bodies to possess figures identical with the figures of the aggregates they form: that a crystal, for example, whose figure is a cube, is formed by the aggregation of a number of infinitely little cubes, &c. But to others this supposition has appeared so improbable, and so unlike the usual simplicity of nature's operations, that they have rejected it, and have had recourse to the more feasible hypothesis,—that the component molecules of bodies are either spheres or spheroidal; that is to say, virtually globular.*

* Strictly speaking, perhaps this observation is applicable to the

Let us take for granted then, that the component molecules of bodies are spheres: with what powers is it necessary to suppose these little spheres to be endowed in order to enable them to cohere, and to form the symmetrical figures we observe among natural bodies? The existence of simple, attractive powers among such a set of molecules, has been already shown to be inadequate to explain the phenomena; there must be some specific powers, determining similar molecules to combine in similar ways, otherwise we cannot imagine the same resulting figures to be produced. In the three small spheres,* Fig. 8, let us suppose that at the points E, E, E, and *e*, *e*, *e*, on their superficies, the spheres are endowed with the following properties; viz. that the similar points, E and E, upon any two of the spheres, have the property of mutually repelling each other; while the dissimilar points, E, and *e*, upon any two of the spheres, have the property of mutual attraction. In such a case, the three molecules will readily combine E, to *e*, as in Fig. 9, but in no other way. Now let us suppose the same three spheres to be endowed with properties at the points M, M, M, and *m*, *m*, *m*, as in Fig. 10, nearly resembling the properties with which they are endowed at the points E, E, E, and *e*, *e*, *e*. Spheres so endowed will aggregate readily, as

Fig. 8.

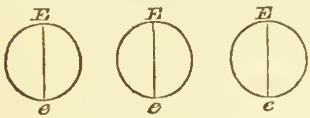
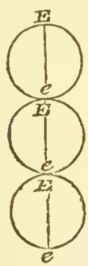


Fig. 9.



figures supposed to be assumed by the influences surrounding the molecules, and by which all their operations are directed; rather than to the absolute figures of the molecules themselves; which, though on account of their rotatory motion virtually exerting spheroidal influences, must, in many instances, have very different figures. Those who wish to study the principles on which spheroidal molecules may be supposed to aggregate into crystalline forms, are referred to Dr. Wollaston's interesting paper on the subject in the Philos. Trans., 1813, p. 51. It may be noticed, however, that the principles we shall advance differ materially, in other respects, from those maintained in the paper referred to; and that the term spheroidal is employed in a popular sense, and is supposed to include every variety of every rounded form, whether ellipsoid, ovoid, or other.

* Or rather sections of spheres, and the same is to be understood of all the subsequent figures.

Fig. 10.

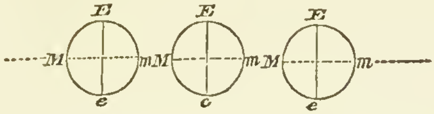
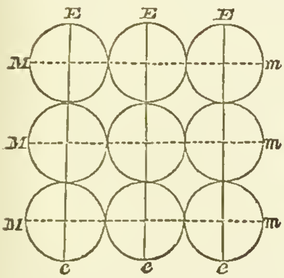


Fig. 11.



in Fig. 11, E, to *e*, and M, to *m*, but in no other way; and thus instead of a single line, we obtain a plate of molecules, one in thickness.* To form the third dimension, or to constitute a solid; it is necessary to assume the molecules as in Fig. 12, to be possessed not only of the attractive points E, E, E, and *e*, *e*, *e*, M, M, M, and *m*, *m*, *m*, but also of the attractive points M′, M′, M′, and

Fig. 12.

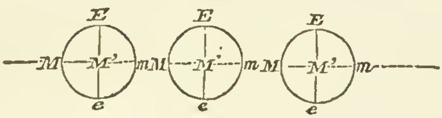
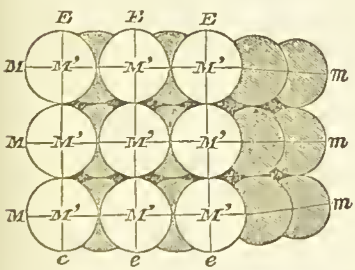


Fig. 13.



m′, *m′*, *m′*, (the point *m′* being supposed to be opposite to the point M′, and out of sight.) Molecules so endowed will readily combine as in Fig. 13, and form a cube, or some figure obviously deducible from a cube, but in no other manner: and in this way, by assuming certain attractive and repulsive points on our spheres or spheroids at appropriate parts of their superficies, it is not difficult to conceive them capable in different instances of forming aggregates of any shape whatever.

* Here it is to be observed that the similar poles E, E, and *e*, *e*, of each pair of molecules being supposed to be repellent within certain limits, as elsewhere will be explained, their absolute contact is pre-

F 2

The force determining the molecules of homogeneous bodies to cohere together is called cohesive force; and from the circumstances before mentioned, it is clear that this cohesive force must possess the characters of polarity. That is, the cohesive force must reside in, or be exerted on, certain points only of the superficies of molecules; the localities of which points we may reasonably suppose to be determined by the mutual relation of the molecules to each other. Thus the cohesive force will be symmetrically located in molecules of similar bodies, and unsymmetrically located in molecules of dissimilar bodies; and the identity or symmetrical position of the potential points in molecules of the same body causes such similar molecules to cohere together. But, as explained in a former chapter, the essence of polarity consists in the co-existence of two opposite or antagonist forces. If, therefore, we assume the existence of a cohesive force among the molecules of similar bodies, we must likewise assume, as we have done in the preceding illustration, the existeuce of a repulsive or divellent force among such similar molecules; and we shall find accordingly, that the assumption of the existence of such a divellent force, among homogeneous molecules, will be necessary to enable us to explain the constitution of the liquid and fluid forms of bodies.

All matter being composed of iunumerable molecules assumed to be more or less of a spheroidal form, bodies however solid, must, as formerly observed, be porous; for since spheroidal particles can only touch one another at certain points; when aggregated, such spheroidal particles must necessarily leave interstices among themselves. In some natural solids these interstices are visible to the eye, particularly by the aid of magnifying glasses. In most substances, however, they are too minute to be visible; though their existence may be inferred from the diminution in magnitude of these solids when subjected to strong pressure—a fact which can be rationally explained only on

vented; and the two molecules are balanced, as it were, between the two opposing and the two attracting forces. The consideration of forces operating in these, and in the other modes, elsewhere mentioned, present some highly interesting and novel objects of research for the mathematician. See Appendix.

the supposition that a portion of the space they previously occupied was interstitial.

By far the greater proportion of material objects as they exist are found in the solid form; and to their numerous and important secondary properties, particularly to their enduring character and stability, we owe much of our comfort and convenience, if not our very being. Even the solid form of water is not without its use in the economy of nature, as will be shown hereafter; whereas if the air were ever to assume the solid form, the whole of the animal creation must instantly perish. Thus the most cursory and general view we can take of the great arrangements of nature, point at once, and unerringly, to the wisdom and power of the Creator.

Of the liquid form of bodies.—We have in the next place to treat of the constitution of bodies in the liquid state. Our notion of liquids in general is, that the molecules of which they are composed still remain in contact, but that their attractive and divellent forces are so neutralized by each other, that the molecules are loosened from the fixed condition in which they existed in the solid form, and are thus enabled to move freely among each other in every direction. This notion of the constitution of liquids suggests the inference, that in passing from the solid to the liquid form, bodies in general must occupy a somewhat larger space; and such inference in the greater number of cases is correct. There are, however, some exceptions to the rule, and water is one of the most remarkable and interesting of these exceptions. In passing from the solid to the liquid form, this indispensable constituent of our globe contracts considerably in bulk. Hence ice is lighter than the water from which it is formed, and consequently swims on its surface—a fact to which we shall have occasion to advert hereafter, as one of the utmost importance in the economy of nature.

That porosity is a property of liquids, even more than of solids, is the unavoidable result of a molecular condition of matter. Accordingly we find that all liquids are not only compressible, but are capable of retaining in solution a variety of matters without any increase of bulk. Thus a certain proportion of salt, and afterwards of sugar, and

perhaps of other substances, may be successively dissolved in a given quantity of water, without apparently augmenting its volume.

In the present condition of our globe the number of liquids bears a small proportion to the number of solids. Indeed, if we except water, and the numerous compounds of which water forms the principal ingredient as well as the cause of liquidity, there are very few others. The chief are certain bodies of organic origin, as oils and various allied substances. There is only one liquid metallic body, the well-known quicksilver; and even most of the compounds of quicksilver are solids. This comparative absence of liquid matter is doubtless of great importance to organized beings. If mineral bodies, for instance, existed in a fluid state, and were miscible with water, they would so contaminate this important liquid, as probably to render it incompatible with organic life. As it is, the small admixture of mineral bodies with water, serves many useful purposes, to which we shall have occasion to refer: and except under certain circumstances such admixtures can hardly be said to interfere with the operations of organized beings.

Of the fluid or gaseous form of bodies.—Bodies in the gaseous or fluid form may be classed under two great divisions, viz. gases, or airs, strictly so called, of which atmospheric air may be considered as the most remarkable; and vapours, of which steam, or the vapour of water, is an instance. Most gases maintain their fluidity at general temperatures of the globe. Vapours are usually the products of higher temperatures, and under ordinary circumstances are capable of only a partial existence. Some gaseous bodies approximate to vapours so nearly in their properties, as to be convertible by pressure into liquids; as for example, the gaseous product of the combustion of charcoal, carbonic acid gas. Other gaseous bodies, as atmospheric air, maintain their fluidity under every degree of pressure we can apply to them.

In fluids the divellent molecular force surpasses the attractive. Bodies therefore in passing from the liquid to the fluid state undergo a remarkable increase of volume. Water, for instance, on being converted into steam, occu-

pies no less than 1,700 times its original bulk. Hence the porosity or interstitial void among the particles of bodies in the gaseous form must be enormous.

If we except atmospheric air, and the minute proportions of carbonic acid gas, and of the vapour of water usually existing in atmospheric air, there are very few other bodies permanently in the fluid state under the usual circumstances of our globe. That this arrangement has reference to the well-being of its denizens, we cannot doubt; for did other gaseous bodies exist in considerable quantity, they must necessarily contaminate the atmosphere and render it incompatible with animal existence. Even those minute proportions of foreign bodies occasionally diffused through the lower regions of the atmosphere in certain localities and seasons, too often prove, as we know by sad experience, the most fearful scourges of our race.

We have thus taken a general survey of the forms assumed by the ponderable materials of our globe, and, at the same time, briefly alluded to the wonderful adaptation to organic existence displayed by such different forms of matter. These wonderful adaptations will be considered more in detail afterwards, and have been only noticed at present with the view of constantly reminding the reader of the great object of this volume, viz., the contemplation of the omnipotence, wisdom and goodness of the Creator.

b. Of the incessant change in the form and constitution of homogeneous bodies.

Among natural objects there are a few both solid and fluid, the forms of which cannot, by any means within our power, be made to undergo change. Such are the diamond among solid bodies, and the air of the atmosphere among fluids. The forms, however, of most homogeneous bodies in nature are either constantly suffering change, or may, by artificial means, be made to undergo such change. Water, for example, under the ordinary circumstances of our globe, is incessantly passing from its solid to its fluid form, and *vice versâ;* nor in this instance of water, do we hesitate for a moment about the cause of these changes of form, viz. change of temperature: change of temperature,

therefore, is the chief cause of the change of form of bodies: and such is the influence of the change of temperature, when extreme, that there are few homogeneous bodies capable of altogether withstanding it. Another cause of change in the form of bodies is pressure. Thus many gaseous bodies, when submitted to strong pressure, become liquids; and *vice versâ*, many fluids from which pressure is removed become gases. Still as compared with heat, the effect of pressure, and of other natural agencies in modifying the forms of bodies, is very slight; we shall chiefly, therefore, confine our observations to heat.

When treating of heat we stated that this powerful agent existed in two states of modification, namely, as Sensible Heat, or Temperature, as it is called, in which form it is measurable by the instrument termed the thermometer; and as Insensible, or Latent Heat. We there detailed the most striking phenomena presented by sensible heat or temperature: the consideration of the phenomena of latent or insensible heat we reserved to be taken along with changes in the form of bodies; during which changes of form the phenomena of latent or insensible heat, are more especially displayed.

Adhering to the familiar instance of water, let us consider what takes place during its passage from the solid form of ice to the gaseous form of steam, and *vice versâ*. If we take a mass of ice cooled to several degrees below the freezing point, and expose it to a regular flow of heat from some external source, the following change of circumstances will be observed. In consequence of the accession of heat, the temperature of the ice will be gradually augmented, till the temperature be raised again to the point of freezing. At this point the ice will begin to be thawed, so as to become water; but notwithstanding heat continues to flow into the melting ice, the temperature of the ice, and of the water to which the ice is reduced by the thaw, will remain stationary at the point of freezing till the whole of the ice be melted; to accomplish which complete melting a quantity of heat equal to 140 degrees of Fahrenheit's thermometer will be found necessary. When the whole of the ice has been melted; if the heat still continue to flow as before, the water will acquire apparent temperature in the same manner in

which apparent temperature had been acquired by the ice; and as the heat continues to flow, the water will continue to increase in temperature and in volume till it arrives at the boiling point. At that moment the temperature ceases to be augmented, however much we may urge the application of heat; and the water is converted into a transparent gas well known by the name of steam. For the conversion of water into steam, however, under the ordinary circumstances of atmospheric pressure, it has been found that about 1,000 degrees of heat are necessary; which large quantity of heat actually becomes latent or disappears; since the temperature of the steam produced never exceeds 212°, the temperature of water at the boiling point. From these observations it appears that the same body, water, under the different forms of ice, water, and steam, must contain very different quantities of heat in a latent or insensible state; which heat, by changing the order of making the experiment, *i. e.* by re-converting steam into water, and water into ice, may be again rendered sensible.

But the fact as regards different bodies is still more striking, than as regards the same body under different forms. Thus, if we mix together the same weight of two bodies at known temperatures, and observe the temperature resulting from the mixture, we shall in no case find that this resulting temperature is the arithmetical mean between the two original temperatures of the bodies mixed, as it ought to be, if the two bodies possessed the same capacities for heat; but a temperature differing in most instances very considerably from such arithmetical mean temperature. For instance, if we mix a pound of mercury at 160°, with a pound of water at 40°; a thermometer, placed in the mixture, will stand at 45° instead of 100°, the arithmetical mean temperature: but if the order of the experiment be inverted, and the temperature of the mercury be made 40°, and that of the water 160°; the mixture will have a temperature further above the arithmetical mean, than in the former instance it was below it; thus, the resulting temperature of such a mixture will be 155°. Hence the same quantity of heat that in the first experiment gives 5° to water, in the second experiment imparts 115° to mercury;

which two numbers are in the ratio of one to twenty-three. That is, in order to increase the temperature of equal weights of water and of mercury to the same extent, we must add twenty-three times as much heat to the water as to the mercury. Similar differences exist in various degrees among other bodies; and in chemical works to which we refer the reader, tables may be found of the specific heats, as they are termed, of a great number of substances, which have been determined with more or less accuracy by chemists.

From these observations it appears, as we have said, that not only the specific heat of the same body varies with its form of aggregation; but that every body has a specific heat peculiar to itself. Hence all the innumerable changes in the forms of aggregation of bodies constantly going on around us, are accompanied by changes in their specific heats; which changes in their turn become the secondary causes of a great many important natural phenomena.

In treating of the crystallized form of homogeneous bodies, we showed that the molecules of which crystals consist exert a species of polarity, capable of determining their cohesion in a certain definite and uniform order. We also observed, that the existence of such a cohesive force among the molecules of homogeneous bodies, must be accompanied by the existence of an opposite or divellent force: this divellent force now claims our attention.

The phenomena presented by water and many other bodies when subjected to high temperatures, sufficiently demonstrate that their molecules are capable of exerting divellent force. We shall attempt to show, however, that such divellent force is actually exerted by homogeneous molecules, when subjected to ordinary influences only.

We have stated, that several gaseous bodies, as the oxygen and azote composing atmospheric air, cannot by any known means be reduced to the liquid or solid form. In these gases the molecular or divellent force, for reasons we cannot discover, far surpasses the corresponding cohesive force; and the permanently fluid character thus imparted to such bodies, is favourable for illustrating the peculiarity of homogeneous forms of matter now alluded to,—that their

molecules exert divellent or self-repulsive forces corresponding with their cohesive or self-attractive forces formerly explained.

It is a law among gaseous bodies, that whatever be their relative weights or specific gravities, they will, when brought together, become, in a very short space of time, equally diffused through each other. Thus if we introduce a heavy gas (*e. g.* carbonic acid gas) at the bottom of a tall vessel, and a light gas (*e. g.* hydrogen gas) at the top of the same vessel, the heavy gas will immediately begin to ascend to the top, and the light gas to descend to the bottom of the vessel, till the two gases are uniformly mixed throughout. So, the two gases oxygen and azote of which atmospheric air consists, though in no way associated, and differing remarkably from each other in their properties and even in their weights, are so equally mixed and diffused through each other over the whole globe, that the most careful analyses do not show any satisfactory difference in their relative proportions. The importance of the above law in the economy of nature is sufficiently evident from this effect on the air we breathe; and we shall have occasion to notice it again. At present these remarkable properties of gaseous bodies have been mentioned from their bearing on the subject now under consideration, viz. the divellent, or self-repulsive force exerted by the homogeneous molecules of bodies.*

The rate of escape or velocity with which a fluid passes through an aperture into a vacuum depends on mechanical principles, and is well understood. Now it has been shown that the rate or velocity with which a heavy and a light gas commingle through a communicating aperture, is identical with the rate of escape or velocity with which gases and all fluids escape through an aperture into a vacuum. This fact, therefore, besides many other results, completely establishes the further corollary, viz. that different gases bear to each other the relation of vacua, and consequently are diffused through each other, not in virtue of any common properties, but in virtue of a self-repulsive force, or resiliency peculiar to each,—a force analogous (but opposite in character) to the self-attractive force which produces the cohesion of homogeneous molecules.

* See Appendix.

Before we proceed, it may be necessary to enlarge still further on the properties of gaseous fluids.

It has been found by experiment that,—within certain limits, the volume or bulk of all perfectly gaseous bodies, is, similibus paribus, equally increased by equal increments of heat, and equally diminished by equal increments of pressure; very striking facts which apparently lead to the additional conclusion that—all perfectly gaseous bodies under the same pressure and temperature contain the same number of self-repulsive molecules. The train of argument on which this conclusion is founded may be thus briefly stated.

If different gaseous bodies contained unequal numbers of self-repulsive molecules, the molecules of those gases which contain the least number, must exert the greatest self-repulsive power: in other words, the expansive energies of the molecules of a gas must increase as their number diminishes; and not only so, but the expansive energy must increase, neither more nor less, but exactly as the number of molecules diminishes. Such a conclusion would be obviously false; for if we imagine an extreme case, and suppose the number of self-repulsive molecules in a given volume of gas to be reduced to a few, or to one for instance, this single molecule must be supposed to exert a self-repulsive power, equal to the self-repulsive power exerted by myriads of molecules under ordinary circumstances.

Another singular property of gaseous fluids, inferred from experiment, is that—all perfectly gaseous bodies, under similar circumstances, and within certain limits, have the same capacity for heat. This general fact, or law, though exceedingly probable, requires further corroboration, and has not been so satisfactorily established as the preceding.*

The reader will have remarked that the divellent energies

* It is proper to observe, that these views were adopted by the author, long before he was aware of the existence of the essays on the subject, by Messrs. Avogadro, Ampere, and Dumas. Indeed he was unacquainted with those of Dumas, which most nearly resemble his own, till he saw them alluded to in Mr. Johnston's recent report on chemistry, in the Transactions of the British Association. Mr. Donovan seems to consider the above hypothesis as untenable; but we think his arguments entirely inconclusive. See Giornale di Fisica, sec. II. tom. viii. p. 1; Annales de Chimie, tom. xc. p. 43; a Treatise on Chemistry, by Mr. Donovan, in

exerted by gaseous bodies, are limited to their perfectly fluid form—a limitation which may require to be further explained.

From the peculiar molecular constitution of gaseous bodies, it must necessarily follow; that when the molecules of which they consist are much approximated by unusual pressure, or great cold; or are much separated, by the removal of pressure, or by great heat; their peculiar motions (on which we have supposed their self-repulsive properties to depend) must in some way be impeded. Accordingly we find that under both these extreme cases, different gases are liable to lose more or less of their perfectly gaseous form and properties. Thus the gaseous compound of carbon and oxygen, termed carbonic acid gas, under ordinary pressure and temperature, possesses all the properties of a perfectly gaseous fluid; yet when subjected to considerable pressure or cold, it ceases to be a gas, and finally assumes the form of a liquid. The same is true of other gases: and, indeed, common air only, and one or two other gases, fulfil all the conditions of perfectly gaseous bodies, even within the limited powers of compression and cold we can command.

The divellent energies are still more conspicuous in those bodies which assume the perfectly gaseous form at high temperatures. Thus, water under the ordinary pressure of the atmosphere, becomes thoroughly a gas only when heated to 212°. This perfectly gaseous form of water is called steam, and is retained by water within certain limits, above its boiling point. But below the temperature of 212° the case is very different: the elastic force of vapour (as steam is more properly termed below the temperature of 212°) rapidly diminishes, so that at 32°, the freezing point of water, this elastic force is scarcely equal to 1-5th of an inch of mercury; and the same given volume of aqueous vapour at 32°, will weigh only about 1-150th of what steam ought to weigh, supposing that water could exist as a perfectly gaseous body at 32°, and under a pressure of thirty inches of mercury. Hence the molecules of aqueous vapour at 32°, must be five or six times further apart than in the perfectly gaseous form of

the Cabinet Cyclopædia, p. 379; and the Introduction to Dumas's Traité de Chimie appliquée aux Arts; which excellent work the author had been prevented from perusing by the nature of the title.

steam;* and so feeble is their self-repulsive force, that, even when thus separated, the aqueous molecules cannot be approximated by slight increase of cold or of pressure without partial coalescence, and the formation of water or ice. The same weakness of the divellent energies prevails among many other bodies besides water, when they are in the imperfectly gaseous form of vapours.

The self-repulsive force exerted by the molecules of water in the liquid, and even in the solid form, though feeble, is not annihilated. Hence, when the space or atmosphere surrounding water, or even ice, is dry, (that is, as compared with water or ice, is a *vacuum*,) the superficial molecules of the water or ice assume their self-repulsive character, and fly off into the surrounding space or atmosphere, till such space or atmosphere is saturated; in other words, till it is incapable of holding any more water in solution. The imperfectly gaseous form, in which water is thus capable of existing at low temperatures, is, as we have said, usually denominated vapour, to distinguish it from steam. The quantity of vapour which can be thus held in solution at any given temperature is fixed and invariable; but the quantity, at no known temperature is absolutely 0, and increases most rapidly with the degree of heat.

Since the quantity of water the air can hold in solution at any given temperature is fixed; when the temperature of a saturated atmosphere is reduced, the superfluous water is deposited in the liquid form; and on the large scale of nature such deposition constitutes rain. Since also the quantity of water held in solution in the atmosphere, increases with the temperature, the quantity of rain which falls in warm climates is much larger than in cold climates; as will be explained more fully under the head of Meteorology.

* Supposing it were possible for steam to exist at 32°, of course at this temperature, its weight would bear to the weight of air, the same proportion it bears at 212°; the proportion, namely, of 5 to 8. One hundred cubic inches of steam, at 32°, ought therefore to weigh 20·49375 grains; or 5-8ths of 32·79 grains, which is the weight of 100 cubic inches of air at 32°. But the weight of 100 cubic inches of steam at 32° is only ·1366 grain, or 1-150th the weight of air. The number of molecules in steam at 32° is consequently only 1-150th of the number of molecules in air at 32°. Hence this diminution of the number of molecules of aqueous vapour, if we suppose them to be diffused equally

The divellent energies possessed by the molecules of water, are displayed likewise in different degrees by tho molecules of a great many other substances; so that only on account of the relatively small proportions in which such substances exist, does our atmosphere retain its salubrity. The molecules of musk, for instance, as well as of many essential oils, and of other odoriferous matters, seem to possess even greater divellent powers than the molecules of water; whence if such ingredients were as plentiful in the air as water is, they would render the world uninhabitable by its present denizens. The same qualities belong, in a less degree, to many scentless but poisonous emanations from unhealthy localities, as malaria producing fevers; the subtle matters causing influenza, cholera, and other epidemic diseases, &c. Such emanations, though trifling in quantity, as compared with the bulk of the atmosphere, and possessing perhaps in general far less molecular divellent power than water, are nevertheless so abundant occasionally, that from the divellent force their molecules possess, they become elevated into the atmosphere; where, aided perhaps by the divellent molecular powers of the aqueous vapour with which they are associated, and by the winds, they become extensively diffused, and prove the scourge of humanity over wide and distant countries.

Lastly, the divellent molecular forces of bodies are not confined to their gaseous form, but are exemplified in liquids, and even perhaps in solids. The molecules of saline, and other matters when dissolved in water, soon become equally diffused through the whole mass, how partially soever they might at first have been mixed with the water,—a fact scarcely to be explained on any other supposition than that the molecules of such bodies possess a self-repulsive property. Such diffusive property would also appear to extend to solids, as we often see crystals containing various foreign matters, the equal diffusion of which through the crystals is difficult to be understood on any other ground, than that there

throughout the same space of 100 cubic inches, must of course, as stated in the text, cause these molecules of aqueous vapour to be between five and six times further apart, than the molecules of air, or of any gas at the same temperature.

exists a species of self-repulsion among the molecules of these adventitious ingredients.

Thus, to the cohesive energies prevailing among similar molecules of matter, we owe the existence of homogeneous solids and liquids; and to their divellent forces, the existence of homogeneous fluids. In other words, had not the forces of homogeneity existed, the whole of the materials of our globe would have been jumbled together in inextricable confusion. There would have been no pure solids, liquids, or fluids, and organic existence would in consequence have been entirely precluded. Further, as regards water in particular, to these molecular forces are due the phenomena of its freezing, condensation, and evaporation, and consequently all the innumerable Meteorological phenomena connected with this important body, which will occupy our attention in a subsequent part of this volume.

Ch. IX.—Of heterogeneous attraction and repulsion; comprising a sketch of the chemical phenomena dependent on the attractive and divellent forces exerted among the molecules of dissimilar matters.

We come now to consider the phenomena of chemical attraction and repulsion, or of the forces reciprocally exerted among the molecules of HETEROGENEOUS bodies. For this purpose it will be necessary, in the first place, to take a short view of the principal elementary bodies known to exist in nature.

§ 1.—*Primary Elements.*

In a preceding chapter we have endeavoured to show, that the minutest fragment of homogeneous matter cognizable by our senses, is composed of innumerable molecules; all of which molecules are exactly alike in size, in shape; alike in properties of every kind; and we deduced from these facts an apparently incontestable proof, that the molecules of matter could not always have existed in their present

cules of matter could not always have existed in their present form; nor have been formed by chance; but that they must have had a beginning; and have been the work of a Creator. Now when we consider the prodigious quantity of matter composing our globe, (to go no further,) or even composing a portion of it, as for instance, the mass of water existing in the ocean; and reflect that every individual molecule of this water possesses properties, exactly like the properties of the drop we formerly contemplated; our argument, already sufficiently convincing, actually overwhelms us with its force. Still however it admits of further corroboration: and we proceed now to show, that all this vast assemblage of molecules, so numerous, so diversified, so extraordinary as they are, may be reduced to a very few elementary groups, which by their endless combinations and separations give rise to all the phenomena of chemistry.

The substances at present considered as elementary, amount to about fifty-six.* Of these elements several possess certain properties in common; though they all differ from one another in subordinate particulars; or in other words, are specifically different. Of the whole number, not above two or three exist, in any great quantity, in an uncombined state, at least in those parts of our globe to which we have access; but the whole are wrapped up, as it were, and have their properties concealed, in compounds. Under ordinary circumstances, most primary elements exist as solids; but some of the more important occur in a gaseous form; and one or two as fluids. A few of them are apparently of so little consequence in the world, that were they annihilated, they would scarcely be missed; while others of them are so obviously necessary to the existence of the present order of things; that the least derangement or change in their proportion, or quantity, would be fatal to creation. Some of these elementary substances exist in such enormous quantities, as to constitute a large part of the whole visible bulk of our globe; while others again, occur in such minute quantity, at least within our reach, as to be obtained with difficulty, and not without elaborate research. With respect to the facility with which the primary elements enter into combination; and the obstinacy with which they unite, they

* Or rather sixty.—G.

differ also, very remarkably; a few of them combining readily in a variety of proportions with almost all the rest; while some of the others can be scarcely made to combine under any circumstances. Lastly, the different effects, which different elementary substances are capable of exerting on organic life, are equally striking. A large majority of them indeed, may, in their simple state, be considered of a deleterious nature; while three or four of them, on the other hand, make organized beings what they are; and are necessary to their very existence.

Such are a few of the leading properties of the primary elements, as we are at present acquainted with them. They have been arranged by Dr. Thomson under three great classes, which he denominates, the supporters of combustion; the acidifiable bases; and the alkalifiable bases; and this arrangement, though not entirely free from objections, we shall for its convenience adopt. The following table presents a summary of this arrangement.

TABLE.

I. *Supporters of Combustion.*

1 Oxygen.
2 Chlorine.
3 Bromine.
4 Iodine.
5 Fluorine.

II. *Acidifiable Bases.*

6 Hydrogen.
7 Carbon.
8 Azote.
9 Boron.
10 Silicon.
11 Phosphorus.
12 Sulphur.
13 Selenium.
14 Arsenic.
15 Antimony.
16 Tellurium.
17 Chromium.
18 Uranium.
19 Vanadium.
20 Molybdenum.
21 Tungsten.
22 Titanium.
23 Columbium.

1. Oxygen, from ὀξὺς, acid, and γεννάω, to generate; from its property of forming acids. 2. Chlorine, from χλωρὸς, green; so called from its colour. 3. Bromine, from βρῶμος, fetid; so called from its strong odour. 4. Iodine, from Ἰοειδὴς, violet; from the colour it assumes in the gaseous state. 6. Hydrogen, from ὕδωρ, water, and γεννάω, to generate. 8. Azote, from α privative and ζωὴ, life; from its being incapable of supporting life. 13. Selenium, from Σελήνη, the moon. 17. Chromium, from χρῶμα, colour; so called from the

III. *Alkalifiable Bases.*

Alkaline Bases.
24 Potassium.
25 Sodium.
26 Lithium.
27 Calcium.
28 Magnesium.
29 Strontium.
30 Barium.

Earthy Bases.
31 Aluminum.
32 Glucinum.
33 Yttrium.
34 Zirconium.
35 Thorium.
36 Cerium.
37 Lantanum.
38 Didymium.

Difficultly fusible Bases.
39 Iron.
40 Manganese.
41 Nickel.
42 Cobalt.

Easily fusible Bases.
43 Zinc.
44 Cadmium.
45 Lead.
46 Tin.
47 Bismuth.
48 Copper.
49 Mercury.

Noble Metals.
50 Silver.
51 Gold.
52 Platinum.
53 Palladium.
54 Rhodium.
55 Iridium.
56 Osmium.

Of these primary elements the first thirteen do not possess metallic properties. All the rest display more or less perfectly the characters of metals. It is foreign to the object of this work to enter into a minute description of these bodies ; we shall therefore content ourselves with such

beautiful colour of some of its salts. 18. Uranium, from οὐρανὸς, the heavens. 19. Vanadium, from *vanadis*, a Scandinavian deity. 20. Molybdenum, from Μολύβδαινα, lead. 22. Titanium, from Τιτανος, slag or cinder. 23. Columbium, from Columbia, in America, where it was first found. 26. Lithium, from Λίθος, a stone. 29. Strontium, from Strontian, the name of a place in Scotland, where it was first found. 30. Barium, from Βαρὺς, heavy. 31. Aluminum, from Alumen, alum. 32. Glucinum, from Γλυκὺς, sweet ; from the taste of some of its salts. 54. Rhodium, from 'Ρόδον, a rose ; from the colour of some of its compounds. 55. Iridium, from Ἶρις, the rainbow ; from the variety of colours assumed by some of its salts. 56. Osmium, from Ὀσμή, odour; from the strong smell emitted by some of its compounds. (To these may be added the metals Niobium, Pelopium, and Ruthenium.) G.

a view of them, as may enable the general reader to form some idea of their properties; and to follow us, without much difficulty, in our subsequent statements.

Of the Supporters of Combustion.—The first five bodies considered primary elements, Oxygen, Chlorine, Bromine, Iodine, and Fluorine, are usually termed supporters of combustion. They have some properties in common; though in other respects and particularly, in their apparent relative influence in the economy of nature, they differ exceedingly. These primary elements are remarkable for the tendency they have, not only to combine with one another; but with almost all the bodies below them in the table; and their process of combination, particularly in the case of oxygen, is usually accompanied by the extrication of more or less of heat and light, and constitutes the well-known phenomenon termed combustion.

(1) Oxygen is one of the very few elementary substances, occurring naturally in the gaseous form; in which form it is found in common air, in the proportion of about a fifth part. Oxygen, as it is the most abundant, may also be fairly considered one of the most important constituents of those parts of our globe to which we have access. From its proneness to enter into combination, it is constantly operating upon, and modifying, everything. By far the greater proportion of mineral bodies, forming the ancient as well as the later strata, contain more or less of oxygen; and in all plants, and animals, oxygen actually exists, as an indispensable primary element. In short, the properties of oxygen, as an element and subordinate agent, are of the highest value; while the numberless contrivances which are observable in nature, to secure, or evade, or modify its operations, are truly extraordinary; and exhibit on the part of their great Contriver, some of the most unequivocal evidences of design, to be seen among his works. Several of the most important of these contrivances, we shall have occasion to notice afterwards; but there is one of so curious and interesting a character, that it may be mentioned here, as an illustration of what we have now said.

The nature and mechanism of the function of respiration will be explained elsewhere; it is sufficient for our present purpose to state, that, by means of a complicated apparatus,

the blood is made to circulate through the lungs; where it is exposed to the influence of the oxygen of the atmosphere. For purposes beyond our comprehension, but probably, in part at least, with a view to the future creation of organized beings, the great Architect of the universe had willed that this principle should exist upon the surface of our globe in a gaseous state: when He created animals, He chose also to render them dependent upon oxygen for their existence; and He effects his object, not by bending this principle to his purpose, by altering its physical or other properties; not by obtaining oxygen from water, or from any of the innumerable compounds into which it enters, which according to our imperfect notions He might have more easily done; but, as if on purpose to display his power and design, He rigidly adheres to the properties, both mechanical and chemical, imparted to oxygen; and to these properties accommodates his future labours! The whole, therefore, of the complicated and beautiful apparatus, connected with the respiration of animals, is most obviously designed and constructed, with reference to the properties of the oxygen of the atmosphere; and altogether, this apparatus affords one of the most striking instances of adaptation and design presented to us in nature.

(2) Chlorine, in its elementary state, is a gas, having all the mechanical properties of common air; but chlorine never occurs naturally in the state of gas. It exists however in large quantities in a state of combination, from which it may be readily obtained by easy chemical processes. One of the most abundant sources of chlorine is common salt; into which it enters in the proportion of about 60 per cent.

As compared with oxygen, chlorine is much less abundant and perhaps less requisite; yet it is doubtful, whether without chlorine, the present order of things could continue. Take for example the familiar instance above noticed. Let us consider the universal diffusion of common salt throughout nature—what the sea would be; or how animals could exist, without it; let us consider these, and the numberless other operations, in which this valuable compound is more or less included, or influences; and we shall be able to form some notion of the part chlorine bears in the economy of

nature. On the other hand, when we reflect, that were chlorine to be extricated from its state of combination, and made to exist, like oxygen, in a gaseous form, it would instantly prove fatal to organized beings; can we fail to be struck with the very obvious design thus displayed, in rendering its quantity and combining powers such as to keep it in a state of union; and by these means, to secure all its useful, without its deleterious properties?

(3) Bromine, and (4) Iodine, the next two substances, are found principally in sea water, and in marine productions; also in certain mineral springs. They appear to exist in very minute proportion, and always in a state of combination. Bromine, under ordinary circumstances, is a deep coloured, red fluid, having a very strong and offensive odour. Iodine is a crystallized solid, volatile by a slight increase of temperature, and forming a beautiful violet vapour. Bromine and Iodine in their properties more nearly resemble chlorine, than oxygen, though they differ materially from both; and their use in the economy of nature is absolutely unknown. We may however observe, that Iodine is now much employed for its medicinal properties.*

(5) Fluorine has been rather inferred, than demonstrated to exist. It occurs principally in the mineral called Fluor spar, in a state of combination with lime. In this and in the other states of combination little is known of the effects of fluorine; but in a state of purity, it is exceedingly

* It may not be amiss to notice, that the author of the present volume first employed the hydriodate of potash (or iodide of potassium), as a remedy for goitre, in the year 1816; after having previously ascertained, by experiments upon himself, that it was not poisonous in small doses, as had been represented. Some time before the period stated, this substance had been found in certain marine productions. It struck the author, that burnt sponge, (a well-known remedy for goitre,) might owe its properties to the presence of Iodine, and this was his motive for making the trial. He lost sight of the case in which the remedy was employed, before any visible alteration had been produced in the state of disease; but not before some of the most striking effects of the remedy were observed. The above employment of the compounds of Iodine in medicine was, at the time, made no secret; and so early as 1818, the remedy was adopted in St. Thomas's Hospital by Dr. Elliotson, at the author's suggestion.

deleterious;* one of its most singular properties is that of corroding glass.

Of Acidifiable Bases.—We pass on now to a very different class of substances, many of which, instead of having the power of supporting the combustion of other substances, are themselves combustible. From their property of generally forming acids, when combined with the supporters of combustion, they have been denominated by Dr. Thomson, acidifiable bases. They are seventeen in number, and the first, perhaps also the most remarkable we have to notice, is—

(6) Hydrogen. This principle, in its elementary state, exists as a gas, having all the mechanical properties of common air. In this state it is exceedingly inflammable; for if hydrogen be mixed with oxygen, and the mixture be exposed to heat, the two gases unite suddenly and violently, with a loud explosion, while the result of the combustion is water. With the other supporters of combustion, hydrogen forms compounds, more or less acid. Hydrogen is the lightest body known, and under the same bulk, therefore, contains less matter than any other body. It does not exist naturally in a separate state, but always in combination; and by far most generally and abundantly in combination with oxygen, in the form of water.

Hydrogen ranks perhaps next to oxygen in importance; at least as far as organized beings are concerned; since, like oxygen, it constitutes one of the primary elements of which they are formed. Hydrogen differs, however, remarkably from oxygen, in not being in its elementary state necessary to the existence of organized beings: indeed gaseous hydrogen is actually incompatible with the existence of animals, if not of vegetables; and its properties as an element have evidently been sacrificed to its properties as a compound; that is, to its properties as water. Hence we have to admire the happy adjustment of the quantities of the two elements to each other, so that the oxygen shall predominate; an adjustment which can scarcely be explained on any other supposition than that of design; for any other cause, as chance, would have been quite as likely to have

* Do not goitre, and some other diseases supposed to arise from malaria, depend on certain combinations of Fluorine?

produced an excess of hydrogen as of oxygen; or at least any thing but the exact proportions required. Lastly, it may be remarked, that to the relative proportions of oxygen and hydrogen prevailing on our globe, more perhaps than to any other subordinate cause, the present order of things owes its stablility. For the proportions of these primary elements are so happily adjusted; and all the numerous operations dependent upon them are, in consequence, so firmly established; that no material change can possibly happen to any part, from an internal cause; but if changed at all, the whole must be changed from without.

(7) Carbon, or charcoal, is a substance too well known in its ordinary state to require description. In its crystallized and pure state, carbon is found to constitute the diamond, the hardest and most brilliant body in nature—a circumstance which certainly could not have been anticipated; but which affords a most striking instance of the effects produced, by the different modes in which molecules of the same matter may be aggregated. Carbon, perhaps more than any other primary element, may be considered as the staminal, or fundamental, constituent of organized beings. This is particularly the case in matters from the vegetable kingdom, which owe their peculiar character essentially to carbon, and their endless varieties to differences in its quantity, or to the modifying influence of the hydrogen and oxygen with which the carbon is associated. In animal productions carbon exerts a similar influence, but its effects are materially modified by the presence of another staminal element, to be presently considered.

Carbon, in some state or other, exists in considerable quantities upon the surface of our globe, but apparently by no means in so large a proportion as oxygen and hydrogen. In the oldest rocks carbon and its compounds are rarely met with. When these rocks were formed, therefore, carbon probably existed only in union with oxygen, in the form of carbonic acid gas. In rocks of later origin, composed of more appropriate materials, and at lower temperatures, much carbonic acid is found in a mineral condition. About this latter period also the abundance of carbonic acid gas, which is the natural food of plants, seems to have favoured the developement of vegetable exist-

ence to a degree of which at present we have no conception. To the remains of this vegetable profusion we owe fossil coals, in which carbon exists in nearly a pure state. In the present condition of our globe, exclusively of what is actually involved in the composition of organized beings, and in the form of fossil coals, by far the greatest proportion of carbon still exists in the form of carbonic acid, which carbonic acid, in union with lime, constitutes common chalk and limestone, two of the most abundant minerals in nature. Carbon or carbonic acid, must also be contained in large quantity in the interior of the earth, as is shown by the profusion which is still, and for countless ages, has been, given off by certain mineral springs.* Carbon in its elementary state is a very inert substance, and is scarcely liable to be affected by, or to affect, organized beings; but with hydrogen and oxygen, it forms gaseous compounds of great activity, which prove instantly fatal to animals respiring them. Such effects, however, appear to be obviated by a beautiful expedient alluded to above, to be more particularly noticed hereafter. In the mean time it may be observed, that though the compound of carbon and oxygen, carbonic acid, is by innumerable processes constantly forming around us in enormous quantities, by some compensating means, it disappears as fast as it is formed, so that the atmosphere, which without this provision, would probably before now have become contaminated by carbonic acid to an extent fatal to animal life, barely contains traces of it.

(8) Azote, or nitrogen, is one of the very few primary elements which exist naturally in an uncombined state. Azote constitutes about 4-5ths, or 80 per cent. of common air; the rest being principally oxygen. The great bulk of this primary element known to us, is confined to the atmosphere; or to animal substances, of which it is a funda-

* In order to give some idea of the proportion of carbon which exists in various common articles, it may be observed, that a pound of charcoal is equal to, and is contained in, rather more than two pounds of sugar or flour, and eight of potatoes or limestone: so that a mountain of limestone contains the essential element of, at least, an equal bulk of potatoes, and of a forest that would amply cover many such mountains.

mental constituent: and it enters very little into natural mineral productions. We have no evidence, therefore, of the existence of azote in the earlier ages of our globe, and it may have been subsequently created. In its pure state, azote is remarkable for its negative properties; that is to say, for the difficulty with which it enters into combination with other matters. Thus, azote is neither combustible, nor a supporter of combustion; is neither acid nor alkaline; possesses neither taste nor smell: nor does it directly combine with any known substance. Yet when made by peculiar management to unite with oxygen, hydrogen, or carbon, azote forms some of the most energetic compounds we possess: thus, mixed with oxygen, it forms atmospheric air, as before observed; united with oxygen, it forms aquafortis, the most corrosive of liquids; united with hydrogen, it forms the volatile alkali, or ammonia, likewise an energetic compound, but of an opposite nature; while its combination with carbon when associated with hydrogen, forms prussic acid, the most virulent of poisons.

Azote may be considered as constituting the characteristic element of animal substances, and as imparting to them their peculiar properties; in this point of view, therefore, it is an element of very great importance. Moreover, the above-mentioned negative properties of azote are evidently of a primordial kind, and seem to have been formed with reference to future creations; which have all been most carefully and rigidly adapted to them. Thus, had the properties of azote not been negative, those of its most important compound, atmospheric air, could not have been negative; and atmospheric air might have been acid or alkaline; or have possessed odour or colour; either of which circumstances would have been incompatible with the present order of things.

(9) Boron, and (10) Silicon, the next two substances, obtain their names from borax, and silex, the natural productions in which they exist in a state of combination. Borax is a saline production, chiefly found in certain lakes in Thibet and China. Boron, the elementary substance obtainable from it, is a dark brown powder, possessing neither taste nor smell, but highly inflammable, at a temperature below a red heat. The resulting compound thus

formed with oxygen is boracic acid. Silicon is the elementary basis of silex or common flint, one of the most abundant of minerals. Silicon is a brown powder very similar to boron in appearance, and like it, inflammable under certain circumstances. By combustion, silicon combines with oxygen, and is converted into silex, which many chemists consider as an acid. Boron and silicon do not exist naturally, but have been obtained by elaborate chemical processes, and only in small quantities. They seem to be more nearly allied to carbon in their properties, than to any other elementary substance.

Borax exists in very small quantities, and its use in the economy of nature is not apparent. Silex, on the other hand, is a most important production; and in its hardness, insolubility, and other refractory properties, we recognize a substance admirably adapted to the purpose for which it has evidently been designed, viz., that of constituting the stamina, or ground-work, as it were, of our globe, and which could not be withdrawn without subverting the whole fabric. Silex is found in small quantities, both in plants and in animals: but does not, like hydrogen, oxygen, carbon, and azote, form a constituent element of organized beings.

(11) Phosphorus, under ordinary circumstances, is a pale amber-coloured substance, very like wax in appearance; but so exceedingly combustible, that it cannot be heated, much less melted, in the open air, without immediately taking fire: the product of the combustion, when complete, is phosphoric acid. Under these circumstances, as may be supposed, phosphorus does not exist naturally, but is obtained by an elaborate process from various matters into which it enters; as for example, from bone earth, or the earthy basis of the bones of animals; and from other saline compounds. Phosphorus exists also in certain minerals in considerable quantities; though on the whole, it is not an abundant principle.

Phosphorus affords another beautiful instance, in which the design has been directed to the properties of the compound, rather than to the element itself. The phosphate of lime, or bone earth, was apparently the thing wanted, to constitute the bony skeleton of animals; and accordingly,

to the properties of this compound, the properties of the element seem to have been sacrificed. Neither lime itself in mass, nor any of its mineral compounds, appear to be adapted for forming a constituent element of a living organized being. It was necessary, therefore, to have a connecting medium, or link, that should unite organization with the mineral constituent; and phosphorus admirably accomplishes this object. Accordingly, we see, that organization goes on in conjunction with lime in the bones of animals, through the medium of phosphorus, quite as readily as in other parts of their system: whereas, when phosphorus is absent, as in shells, and in other deposits of carbonate of lime, the carbonate of lime is extra-vascular, and seems to form no part of the living system. There are also other important offices which phosphorus evidently performs in the animal economy: some of which we shall notice in another part of this treatise.

(12) Sulphur. This well-known substance is one of the very few that exist naturally in an elementary state. Sulphur is an abundant, and probably important, element in the economy of nature; as it not only exists in large quantities in the mineral kingdom, but in a greater or less proportion, in almost all animal, and in many vegetable matters. Its uses, however, at present, are very imperfectly understood. Sulphur combines with hydrogen, and forms a very deleterious gaseous compound. Its combinations with oxygen are generally acid, and very active in their concentrated form; but not poisonous.

(13) Selenium, the next substance, is found in very minute quantities, generally associated with sulphur; which in its properties it somewhat resembles: or rather, perhaps, it appears to constitute the connecting link between sulphur and the metals. The uses of selenium in the economy of nature are unknown; but we shall have occasion afterwards to refer to its compound with hydrogen; which is even more deleterious, than the compound of sulphur with that element.

(14) Arsenic, in its pure state, is a metalloid, or imperfectly metallic substance, having much the appearance of polished steel. In the form in which it is popularly known, as white arsenic, it is combined with oxygen; and con-

stitutes one of the most deadly poisons. Arsenic exists in certain minerals in considerable quantities; but seems, in every state of combination to be incompatible with organic life.

(15) Antimony, is usually found, associated with sulphur: the compound of antimony and sulphur was for a long time considered as the metal itself. In its pure state, antimony has a bluish-gray colour, and possesses considerable metallic splendour; but in this form, it seldom occurs in nature. The compounds of antimony are active medicinal agents; and some of these compounds are much employed in medicine.

(16) Tellurium, (17) Chromium, (18) Uranium, (19) Vanadium, (20) Molybdenum, (21) Tungsten, (22) Titanium, and (23) Columbium, the next eight substances, are metals, for the most part obtained by elaborate processes, from rare mineral productions. The most valuable, as well perhaps as the most abundant, of these substances, is chromium; the compounds of which, from the splendour of their colours, have been lately much employed in the arts. Like selenium, arsenic, and antimony, these metals all combine with oxygen, &c., and form compounds possessing many of the characters of acids. It may be remarked of all these substances, that at present their use in the economy of nature is beyond our knowledge.

Of Alkalifiable Bases.—The next thirty-one substances have been denominated by Dr. Thomson alkalifiable bases: these substances have been so denominated, because the compounds formed from all of them, partake more or less of the character of the compounds formed from the substances in the first subdivision or family in the class, which are termed alkalies. Dr. Thomson has subdivided the alkalifiable bases into five families, having characters sufficiently indicated by their designations: they are the alkaline bases; the earthy bases; the difficultly fusible bases; the easily fusible bases; and the noble metals.

Of the Alkaline Bases.—(24) Potassium, and (25) Sodium, are the metallic bases of the two well-known alkaline substances, potash and soda; which are compounds of these metals with oxygen. Such, however, are the powerful affinities of the metallic bases for oxygen, that they no where

exist naturally upon the surface of our globe. The same may be also remarked of potash and soda; the powerful alkaline properties of which substances prevent them from existing uncombined. In this respect, the compounds potassium and sodium form with oxygen, present a striking contrast with the compounds they form with the analogous principle, chlorine; the compounds of potassium and sodium with chlorine, (the latter of which constitutes common salt,) are remarkable for their permanent character; and for the little tendency they have, in general, to enter into a further state of combination. Besides their remarkable avidity for oxygen, potassium and sodium possess some other unusual properties. Potassium, for example, is so light, that were it compatible with water, it would swim on the surface of that fluid; a circumstance we can hardly imagine to happen with a metal.

Potash and soda, in all their forms, are most important principles. Their existence can be traced to the earliest formations of our globe, and is evidently necessary to the present order of things, both mineral and organized; for there are few organized beings, that do not contain more or less of them. Potash is found more particularly in plants; but exists also in animals: while the universal presence of soda in animals, in the form of common salt, has been already referred to, and is generally known. These alkalies present us with a beautiful instance of adaptation for the purposes they seem destined to fulfil in the operations of nature. Had they been solids; or had they formed solid compounds, like many of the preceding principles; they would have been totally unfitted for their peculiar office: that is to say, for forming a constituent element of the fluids of organized beings.

(26) Lithium, is the metallic basis of the alkaline substance termed lithia. This newly discovered substance is intermediate in its properties, between the alkalies and the earths, to be next considered. It has hitherto been met with, in some rare minerals, and in small quantities only.

(27) Calcium, the metallic basis of lime, can be obtained only by a troublesome and difficult process; and, of course, does not exist naturally. It is a white metal like silver, and by union with oxygen, is readily convertible into lime.

This well-known element exists in the greatest abundance in nature; not as quick-lime: but united with carbon and oxygen, in the form of common lime-stone, marble, &c.

The great value of lime in the economy of nature, is too obvious to require notice; and it is only necessary to revert to the fact, that this earthy material is one of the very few mineral productions, capable of forming a part of a living organized being; at least in any quantity. This earth, as formerly noticed, constitutes with phosphorus and oxygen, the basis of the bones of animals; and with carbon and oxygen, all the endless variety of shells, and similar products. Thus the properties of lime, furnish another striking instance of adaptation to a particular purpose. The compounds of potash and soda are all very soluble in water, and hence are chiefly confined to the fluids of animals; in which their presence is indispensable. But a solid framework, or skeleton, was necessary to the existence of more perfect animals; and as this framework could not be formed from the soluble potash or soda; the introduction of another mineral substance, possessed of the requisite properties, was necessary. Now lime, having some compounds solid, and others fluid, is admirably adapted for the purpose. Lime accordingly has been chosen: the lime is carried, in a state of solution, to the spot where it is required, and is there converted into a solid; while by the same agency, this solid, having fulfilled its office, is again converted into a fluid and removed!

(28) Magnesium, is the metallic basis of the well-known earth, called magnesia. It is said to resemble calcium in its properties; and like that element does not exist naturally, at least upon the surface of our globe. Magnesia, though occurring most abundantly in nature, and entering very largely into the composition of rocks; never, like lime, constitutes masses of great extent, in the same simple state of combination; that is to say, there are no mountains of magnesia; as there are of chalk and of limestone.

Magnesia, like the three preceding mineral substances, potash, soda, and lime, seems to be indispensable to the existence of organized beings; as there are few in which traces of this earth are not met with, generally associated with phosphorus. Its uses, however, are less obvious than

those of the three other substances, and indeed may be said to be unknown: though there is reason to believe, that it is most intimately connected with the operations of organic life.

(29) Strontium, and (30) Barium, the metallic bases of the two alkaline earths, strontia, and baryta, are allied to calcium and magnesium in some of their properties; but differ exceedingly from them in others. The combinations of strontium and baryum with oxygen exhibit a still more decidedly alkaline character, than the combinations of either calcium, or magnesium; and in consequence, like lime and magnesia, strontia and baryta exist only in further states of combination; most generally united with carbon and oxygen, or with sulphur and oxygen. Compared with lime and magnesia, strontia and baryta exist but sparingly; and neither of them has anything to do with organization; indeed many of the combinations of barium are virulent poisons.

Of the earthy Bases.—(31) Aluminum, is the metallic basis of the earth alumina; the characteristic ingredient of the well-known salt, called alum. The metallic basis, like the preceding, nowhere exists; but alumina, the compound of aluminum and oxygen, is one of the most abundant productions of nature; and constitutes an ingredient in by far the greater number of rocks and soils upon the surface of the globe. The different kinds of clay, also, from which bricks, earthenware, &c., are formed, consist chiefly of this earth, in different states of purity; so that it is a substance of great utility and importance.

Alumina appears to have little to do with organization; at least, it is not known to form a necessary constituent of any organized being, either vegetable or animal; though it is in constant communication with organized beings; and appears to be almost necessary, in some indirect way, to their existence. This fact is remarkable; for since alumina does not appear to be poisonous, it could scarely have been so completely excluded from living bodies, except by some design beyond our comprehension.

(32) Glucinum, (33) Yttrium, (34) Zirconium, and (35) Thorium, the four next primary elements, are the metallic bases of substances, usually considered as possessing the

characters of earthy bodies, which substances are denominated Glucina, Yttria, Zirconia, and Thorina. All these earthy bodies appear to exist very sparingly in nature; and are only found in some rare minerals. Glucina has not been hitherto met with, but in the precious stones denominated the emerald, the beryl, and the enclase; yttria and thorina in some rare Swedish and Norwegian minerals;* and zirconia in the jargon, or zircon from Ceylon, and in the hyacinth. These earthy bodies more nearly resemble alumina, than any other substance.

(36) Cerium, (37) Lantanum, and (38) Didym or Didymium, are metals very little known, and have hitherto been obtained, in minute quantities only, from cerite, a rare mineral occurring in Sweden and in Greenland.

Of the difficultly fusible Bases.—(39) Iron, one of the most important, is also one of the most abundant elementary substances in nature. Iron is met with occasionally in the metallic state; but most generally, it is found mineralized in various ways; and can only be obtained pure by an elaborate process. Iron exists in minute quantities in almost all vegetable and animal products; particularly in the blood, though its mode of combination, as well as its precise use, are little known.

Iron may justly be considered as the most useful of all the metals; and the one, that has perhaps contributed more toward the civilization of mankind, than any other. To form some idea of its use, we have only to reflect, what would happen if it were annihilated. What substitute could be found for iron, in all the numerous instances in which it contributes to the wants, or to the comforts, of mankind; particularly through the medium of tools, of almost every one of which iron constitutes the essential material? In short, when we contemplate all the circumstances connected with this metal; its abundance, the manner in which it is mineralized, and the occasion which it thus gives to human ingenuity to extract it from its ores; its wholesomeness, (for many of the metals are poisonous); its properties, par-

* According to some recent observations, the substance hitherto called yttria is a mixture of three different metallic oxides, viz., of the oxide of yttrium properly so called, and of the oxides of two new metals termed erbium and terbium.

ticularly its extraordinary tenacity, its strength, its property of welding, of being converted into steel, and in this form of being tempered to any degree of hardness we choose; its magnetic properties, &c.,—when we contemplate all these circumstances, it is impossible not to be struck with such varied usefulness; and to consider iron, not only as an article evidently designed for the benefit of man; but as the instrument by which he should conquer, and govern the world; and thus be enabled to place himself, where it was evidently intended he should be, at the head of creation.

(40) Manganese, somewhat resembles iron in a few of its properties. Manganese may be obtained from its ores by an elaborate process: but in this form it is little known or used. Manganese exists in minute quantities in certain mineral waters; and in a few animal products. The combinations of this metal with oxygen are employed in the arts; the chemist also frequently procures oxygen for his experiments, from the ores of manganese. Though much diffused, manganese is not a very abundant metal, at least compared with iron; and is apparently of much less use in the economy of nature.

(41) Nickel, and (42) Cobalt, are two metals somewhat resembling each other in their properties; and their ores are often associated. It is remarkable also, that nickel and cobalt are both generally found combined with iron, in those mineral bodies which occasionally fall from the atmosphere; and which are considered to be of meteoric origin. Like iron also, both these metals are capable of becoming magnetic. Cobalt is used in the arts, and is the basis of the blue colour upon our earthenware; but neither this metal, nor nickel, are to be compared with iron in point of utility: nor are they very abundant productions.

Of the easily fusible Bases.—(43) Zinc, (44) Cadmium. These two metals are generally found together in nature, and are much alike in their properties; but cadmium is comparatively less abundant than zinc, and has been only recently discovered. Zinc is a metal easily melted; of a bluish white colour; and of a lamellated brittle texture: though by peculiar management, it may be rendered malleable. It is an ingredient in the well-known metal, brass;

and in this form is much used, and is of considerable utility.

(45) Lead. This well-known metal is not found in its metallic state, but its ores are very abundant; and most of the lead of commerce, is extracted from the mineral, called galena, which is a compound of lead and sulphur. The general properties of lead and of its compounds, render it of considerable importance: but its poisonous properties are a great draw-back to its usefulness. Why lead, and other mineral matters, should have been constituted poisonous, is a question beyond our reach; and all we can at present venture to state on this and on similar points is, that man is an intelligent being, and as such possesses the requisite knowledge and power to avoid, if he chooses or wills, the deleterious properties of lead and other poisonous substances.

(46) Tin. This useful metal has been employed by man from the most remote antiquity; though it nowhere exists naturally in its metallic state; but usually in conjunction with oxygen. Tin is not a very plentiful metal, being apparently confined to a few localities only; one of the most noted of which, is Cornwall. Tin is innoxious, and is therefore much used for domestic purposes.

(47) Bismuth, occurs in nature, both in the metallic state, and in various states of combination. Bismuth has a reddish white colour; a lamellated brittle texture; and is easily fusible. Bismuth is not a very abundant metal; nor is it much employed.

(48) Copper, occurs in nature in the metallic state, but much more frequently mineralized, especially with sulphur. We derive great advantage from copper both in its pure and mixed states; and in consequence of its valuable properties it is much used in the arts. With zinc, copper forms brass; with tin, bellmetal; both well-known compounds. Copper has been lately said to exist in very minute quantities in organic nature; but whether as an accidental, or as an essential ingredient, is not known. The compounds of copper are poisonous; but these poisonous properties, like the poisonous properties of lead, can be easily obviated, and guarded against.

(49) Mercury. This well-known fluid metal occurs in the metallic state; but more frequently mineralized, espe-

cially with sulphur. The importance of mercury in the arts, and as a medicinal agent, need scarcely be mentioned here. The fluidity of mercury presents a beautiful instance of the endless diversity of nature; and adds much to its value and usefulness. Mercury exists in considerable abundance; though much less so, than many of the preceding elementary substances.

Of the noble Metals.—(50) Silver, and (51) Gold, and their uses are too well known to require description. Independently of their beauty, which is pre-eminent, silver and gold are less liable to change than most other bodies; properties, which, together with their scarcity, have rendered these metals by the common consent of mankind in all ages, the universal representatives of value. With some such benevolent regard to man's convenience, silver and gold were probably created; for in the economy of nature these metals apparently act a very unimportant part, and might even be removed without deranging the present order of things. How different in importance are these noble metals from many of the little esteemed elements before described, many of which could not be annihilated without the destruction of all the rest. How different are they even from iron, in intrinsic value, that humble medium by which man has been enabled to conquer the world! Silver and gold are both met with in the metallic state; but silver also occurs mineralized. When pure, these metals are too soft for the manufacture of coins, for which they are chiefly employed; and are alloyed with a certain proportion of some other metal, generally copper, which imparts the necessary hardness.

(52) Platinum, (53) Palladium, (54) Rhodium, (55) Iridium, and (56) Osmium, are metals usually found associated in small quantities, chiefly in certain districts of South America; but recently also in the old world. Platinum, the most abundant and important of these metals, is the heaviest body in nature. Platinum is acted on with difficulty by most ordinary agents; but it may be welded by heat—properties which render platinum exceedingly valuable for many purposes; and make us regret, that it is not more abundant. Palladium somewhat resembles platinum in its characters; but occurs less frequently. The other three metals exist in

very minute quantities; and their properties are imperfectly known.

We have thus taken a summary view, of the different primary elements met with upon the surface of our globe; and of their leading properties. We shall, in the next place, consider the laws by which the union of these primary elements with one another are regulated.

§ 2.—*Of the laws of Heterogeneous and Homogeneous union.*

As the following remarks on the laws of heterogeneous and homogeneous union can scarcely be so given as to prove a source of interest to the general reader, he is desired to pass them over and to turn to the last chapter of this Book; where he will find a brief sketch of the evidence which the various subjects treated of furnish in favour of design, and of the wisdom and power of the Creator.

In the preceding chapters we have attempted to explain the following general facts or laws:

First law. That every molecule of matter, whether primary or compounded, possesses two kinds of polarity; viz. HOMOGENEOUS polarity, proper to molecules of SIMILAR matter, and determining the phenomena of cohesion and divulsion; and HETEROGENEOUS polarity, proper to molecules of DISSIMILAR matter, and determining the phenomena of chemical attraction and repulsion; and that all the phenomena of Homogeneity and of Heterogeneity, however complicated they may appear, are binary or DUAL; *i. e.* immediately result in every instance from forces mutually exerted between only two molecules of matter.

Second law. That all gaseous bodies, under the same pressure and temperature, contain an equal number of self-repulsive molecules.

We have now to announce another satisfactorily established general fact or Law, viz.—

Third law. That the same volume, by measure, of any gas always combines with either precisely a similar volume by measure of the same, or of another gas; or with some multiple, or submultiple volume by measure, of that gas; (in other words, with twice, or thrice, or half, or a quarter,

as much, &c.) but not with any intermediate proportion; and further, that the volume by measure of the resulting compound, always has reference to the volumes by measure, of the constituent elements of the resulting compound.

After briefly illustrating this third law, we shall point out some of the important inferences deducible from the whole three laws taken together.

As a means of illustrating the third law just cited, let us take our old example of water.

Water has been shown by repeated experiments to consist of one volume by measure of oxygen gas, and two volumes by measure of hydrogen gas; and so invariably have these results been obtained, that we cannot suppose water to consist of any other proportions of these elements. It has also been shown by equally conclusive experiments, that the resulting water, if in the state of steam, occupies exactly the space of two of the three original volumes by measure; so that one original volume by measure has disappeared. Now let us consider attentively, what must have happened during these changes. One volume of oxygen gas has contributed to form twice its volume by measure of water; which two volumes of water, according to the second law, must consist of twice the number of self-repulsive molecules contained in the one volume of oxygen; yet every one of these molecules must contain oxygen; because oxygen is an essential element of water: it follows, therefore, irresistibly, that every self-repulsive molecule of oxygen, has been divided into two; and consequently, must have originally consisted of at least two elementary molecules somehow or other associated, so as to have formed only one self-repulsive molecule. This conclusion, which seems to flow inevitably from our premises, is most important, as we shall see immediately; and enables us to throw no small light upon many points deemed obscure. In the meantime, let us consider briefly the nature of the compound self-repulsive molecule of hydrogen. Whether the self-repulsive molecule of hydrogen be double or not, cannot be inferred from the composition of water, as above stated; but this double state of the molecule of hydrogen may be demonstrated from other compounds, into which hydrogen enters. Thus muriatic acid gas is composed of one volume by

measure, of chlorine gas, and one volume by measure of hydrogen gas; which two volumes unite without any condensation, and form two volumes by measure of muriatic acid gas: now, in this case, it is evident that not only the self-repulsive molecule of hydrogen, but also that the self-repulsive molecule of chlorine, must be double at least, like the self-repulsive molecule of oxygen above mentioned; and the same double state of the molecules might be shown with respect to other gaseous bodies.

We have said above, that the self-repulsive molecules of oxygen and of hydrogen, are at least double; but the probability is, that they are in reality much more compounded; as the following observations will show.

The molecule of water, on entering into combination, is often found to be divided into two, or three, (perhaps more,) parts. Now as we cannot admit the division of an ultimate molecule, or atom; we must of course conclude, that the molecules of oxygen and of hydrogen, are much more compounded than as above represented; and must each of them contain at least, three component, or sub-molecules. Hence the molecule of water will consist of at least nine component sub-molecules (viz. three of oxygen, and six of hydrogen,) which we may suppose to be associated—in the first place, the hydrogen with the oxygen, chemically; and afterwards the three sub-molecules of water with one another cohesively, so as to constitute one spheroidal molecule: in a manner, it would not, perhaps, with a little ingenuity, be difficult to represent mechanically.*

Precisely the same laws of union may be supposed to prevail among the molecules of solid bodies, as they actually exist around us. Thus, let us take a crystal of oxalic acid, a substance familiar to most readers, as an instance for illustration. This acid is composed, according to the present language of chemists, of two molecules of carbon, and three of oxygen, which, by combining, form the acid; while,

* When bodies, as, for example, water, are subjected to intense degrees of heat, it is not improbable that in many instances the self-repulsive molecules are more or less separated into their constituent sub-molecules; in which case, of course, the bodies may be supposed to exhibit altogether different elastic powers, and laws of expansion.

to complete the compound molecule, and to adapt it for crystallization, three molecules of water are required to be somehow associated, with each of the molecules of the acid. Now in this case, we suppose, that the two molecules of carbon, (each of which is perhaps already made up of several sub-molecules,) are cohesively associated into one symmetrical super-molecule; that the three molecules of oxygen, associated in a similar manner, are then combined chemically with the super-molecule of carbon, and thus form by their union a molecule of oxalic acid; finally, that the three molecules of water are cohesively associated into one super-molecule, which unites chemically with the molecule of oxalic acid; and thus completes the molecule of the acid, as it is presented in the crystallized form.*

Such are the views we have been induced to take of the nature of homogeneous and heterogeneous molecular combinations: whether right or wrong, they have the merit of being exceedingly simple, and consistent with themselves, throughout; which can hardly be said of any others, with which we are acquainted. Indeed much reflection on the subject, for many years past, has satisfied us, that, these combinations can be rationally explained, only in some such manner as we have supposed. Any lengthened argument, however, on the subject here, would be quite out of place; we shall therefore confine ourselves to the following observations.

1. The above view of the molecular constitution of bodies, naturally suggests the question: do the sub-molecules, which we suppose to unite together cohesively, and form the self-repulsive molecule of oxygen and hydrogen for instance, possess the same properties as those of oxygen and hydrogen? or do they possess different properties? These questions, in most instances, cannot, in the present state of our knowledge, be satisfactorily answered; though there is every reason to believe that the properties, both of the sub-molecule, and of the super-molecule, generally differ from the properties of the molecule itself: but that

* The chemical reader will observe that the above constitution of the oxalic acid crystal is given for illustration only. The actual molecular constitution of this crystal may be, and probably is, very different.

the differences are rather of a specific, than of a generic character.* Thus chemists have shown that different volumes of the same gaseous body, termed carburetted hydrogen, combine together, and form various compounds: we have, for example, a gas, one volume of which contains two volumes of carburetted hydrogen; another, one volume of which contains three, and another four, of the same gaseous body. Now the sensible properties of all these compounds, though resembling each other in some respects, are yet specifically different; and since the compounds are all composed of the gaseous body in different proportions; these differences must be considered rather as the result of cohesive, than of chemical, union. Thus the supposition, that both the sub-molecules, and the super-molecules of bodies, may possess properties different from one another, and from the standard molecule, is rendered exceedingly probable by the above facts; and if our space admitted, it would not perhaps be difficult to bring forward other facts of the same kind. This however would be foreign to our purpose; we shall only remark, that a great many curious circumstances, at present but very imperfectly understood, evidently appear to be referable to a similar principle.

2. Although we have thus rendered it probable, that the molecules of bodies considered at present as elementary, are immediately compounded of many others, more or less resembling them; yet it is obvious, that there must be a point at which these, and other elements, exist in a primary or ultimate form; and beyond which, if the elements can be supposed to be subdivided, they must become something altogether different. In this respect, therefore, the views we have advanced, accord generally with the views at present entertained; and the only respect in which our views differ, is in supposing, that the self-repulsive molecule, as it exists in the gaseous form, does not represent the ultimate molecule; but is composed of many sub-molecules. With respect to the nature of the sub-molecules

* As already stated, what we term the sensible properties of bodies are, in all instances, the result of a great number of molecules acting together at the same time; hence below a certain point, mere difference of numbers may be supposed to produce a change in sensible properties, not only in degree, but in kind.

of those bodies, which we at present consider to be elements, as, for instance, of oxygen; they may naturally be supposed to possess the most intense properties, or polarities. Indeed, such sub-molecules may be imagined to resemble in some degree, the imponderable matters, heat, &c., not only by their extreme tenuity, but in other characters also; and this very intensity of property and character may be reasonably considered as one, if not the principal reason, why they are incapable of existing in a detached form. Lastly; are not these ultimate and refined forms of matter extensively employed in many of the operations of nature; and particularly in many of the processes of organization?

3. By supposing that these laws of combination are not confined to elementary bodies, but extend to all others throughout nature; and that bodies, however complicated they may be, always act as simple molecules, and combine dually, with reference to their volume in the gaseous state; we are enabled in some degree, to explain that endless variety of property, and condition, which we see around us. For a new compound molecule formed by an assemblage of similar molecules, may be supposed to possess heterogeneous properties, and be capable of combining with other molecules chemically, and of thus entering into a long and novel series of combinations: while these combinations again in their turn, may be imagined to lead to others; and so on, till the variety becomes extreme. Indeed, were not such combinations limited by the very nature of things themselves, no two substances would probably possess the same properties. As it is, most of these compounds are incapable of separate existence: thus the compound super-molecules of water in the crystal of oxalic acid before referred to, are incapable of separate existence: if they could exist separately, would they assume the form of water?

4. It might not be difficult, though not very safe, or prudent, in the present state of our knowledge, to speculate on the crystalline forms assumed by different bodies, with reference to the principles we have advanced. We shall therefore not touch upon this part of the subject, further than by observing, that the cohesive force of homogeneity, though supposed to possess some peculiarity, as existing among

the molecules of different bodies, is neverthelcss essentially but of one kind. When therefore, the molecules of different bodies are of the same size (or rather of the same weight,) they may be naturally supposed capable of associating themselves into the same form; and if these molecules happen to be mixed together, they may even enter indiscriminately into the same crystal. Hence arises what has been termed the isomorphism of bodies; while if there be a near approximation, but not an exact coincidence in the above relations, the approximate relations may, on the same grounds, be supposed to give origin to plesiomorphism, that is to say, to a near approach to a similarity of form.

5. With respect to the nature of the circumstances which determine the characters and modes of existence of bodies, we know very little. We are almost equally ignorant also, of the nature of the causes which determine the cohesion of similar molecules into the crystalline form. A variety of arguments might, however, be brought forward, which appear to show, that the size, and shape, of the molecules, have a great deal to do with crystallization; certainly, at least, the molecules must be supposed to have a size, and shape, somehow or other adapted for the modes in which they are arranged; otherwise they could not be capable of such an arrangement. The cause of this similarity of size, and shape, is unknown; but it most probably depends upon the similarity of weight (Isobarism), of the molecule: that is to say, upon the relation or identity of the absolute quantity of matter which the molecule contains; which relation, as far as we can perceive, is not only the sole circumstance common to the molecules of different bodies; but that which, of all others, is the most likely to produce identity in the size, and shape, of these molecules.

6. When the molecules of bodies in solution do not happen to possess the requisite size and shape for cohesion, there is, from the phenomena, reason to believe, that they occasionally possess the power, as it were, of making up the necessary form, by attaching to themselves the molecules of other bodies. Now, bodies so attached may be considered as acting a sort of complementary part; that is, these attached bodies may be supposed to complete the

size, or figure, of the molecule; so as to adapt it for combining in a certain manner. Thus, the water of crystallization, (and perhaps occasionally other matters), appears in the greater number of instances to perform an office of this kind; and to be, in fact, strictly complementary to that particular size, and figure, of the molecules, which may be supposed to be requisite, for enabling them, not only to combine the more readily with each other; but at the same time, to form a symmetrical solid, or crystal.*

One or two other circumstances, connected with this part of our subject, will be better understood, after we have considered, a little more in detail, the combinations of bodies with reference to their weights; and with reference to the absolute quantity of matter, they contain. To this most interesting inquiry, therefore, we shall in the next place proceed, confining ourselves, however, as before, chiefly to the elements of water, hydrogen and oxygen.

It has been found by experiment, that the same volumes by measure of different bodies in the gaseous state, have very different weights. Thus, for instance, a volume of oxygen weighs sixteen times as much as the same volume of hydrogen. Hence, as the number of self-repulsive molecules in each of these gases, is presumed to be the same; the weight of the self-repulsive molecule of oxygen must of course be sixteen times greater, than the weight of the self-repulsive molecule of hydrogen; and as a general law:

Fourth law. The weights of the self-repulsive molecules of all bodies, are as the specific gravities of these bodies in the gaseous state; or bear certain simple relations to these specific gravities.

* There is every reason to believe, that one variety of isomorphism is effected on the principles here stated; and that the molecules of different substances, by attracting to themselves different quantities of water or of other matters, may ultimately make up compound molecules, similar to those of the bodies with which they may happen to be mixed. The molecules of extraneous substances may thus enter into crystalline forms different from their own peculiar forms. Such a state of things is calculated to baffle the mere chemist, however expert, though it is probable, that if carefully examined and understood, an intermixture of this kind might be detected, by the optical properties of the crystal.

This relation in weight among the molecules of bodies, constitutes the basis of what is called, the Atomic Theory, proposed, some years ago by Dr. Dalton: who established the very important fact, that bodies do not, as formerly supposed, combine at random, but in definite proportions by weight; and if the preceding doctrines be well founded, it is evident that the molecules of bodies cannot combine otherwise.* Since however water is composed of one volume of oxygen, united with two volumes of hydrogen, the relative weights of the hydrogen and the oxygen in water will be, not as 1 to 16, but as 1 to 8 only; while the weight of the self-repulsive molecule of steam, will be 9. Hence, since one, or the other, of the elements of water, is usually made the basis of the atomic numbers, this difference between the volumes and the combining weights of these two elements, has produced considerable confusion, and has given rise to much needless discussion. For the sake of mere convenience, it is certainly preferable to consider the two volumes of hydrogen, as one atom (to use the language of Dr. Dalton); in which case, oxygen will be 8, and water 9; but, supposing the principles we have advanced be well founded, a strictly philosophical arrangement would require, that the volume in all instances should be made the molecular unit; in which case, the relative weights of the self-repulsive molecules of hydrogen and oxygen, as above mentioned, will be as 1 to 16.

In this country, we have already said, two volumes of hydrogen, are usually considered as one atom, or unity, in which case, oxygen is 8; but some have chosen instead of hydrogen, to make oxygen unity, or 10; in which case, hydrogen, of course, will be the one-eighth of 1, or of 10; that is to say, ·125 or 1·25; and water, instead of 9, will be 1·125, or 11·25. It matters not which of these series of numbers, or whether any other series be employed, provided that the same relative proportions be observed among them; but the first series is that most generally adopted, and is upon the whole, the most con-

* The reader is referred to "An Introduction to the Atomic Theory," published by Dr. Daubeny, Professor of Chemistry at Oxford; for an interesting and able inquiry into the principles of this theory.

venient. In the above manner, the atomic weights, as they are termed, of all bodies capable of assuming the gaseous form, can be easily obtained; but in those bodies which do not assume the gaseous form in their simple state, but in some state of combination only, we are obliged to deduce the weight of the primary molecule, from that of the compound. Thus carbon, in its elementary state, is incapable of assuming the gaseous form, but when combined with oxygen, the result is carbonic acid gas, one volume of which gas, weighs 22 times as much, as our standard two volumes of hydrogen. Now it has been found by other experiments, that of these 22 parts, 16 are oxygen. The remaining 6 parts must, therefore, be carbon, and accordingly 6 is the number upon our scale representing carbon, and the proportion with reference to which this body always enters into composition.

In the case of bodies, as for instance lime, which are incapable of assuming a gaseous form, either alone, or in combination, we are obliged to trust solely to analysis; thus common marble or carbonate of lime, as it is termed by chemists, is found to be composed of 22 parts of carbonic acid, and 28 parts of lime; 28 therefore represents upon our scale the atomic weight of lime, and so of all others.

It may be observed, that we have spoken as if the atomic weights of bodies were related to one another by multiple, and were all multiples of some common unit. Now this opinion has been maintained by some, while it has been denied by others, who, admitting that multiples in weight are necessary to the union of similar molecules, both chemically and cohesively, will not admit, that multiples in weight are necessary to the union of dissimilar molecules. The matter is one which, in the present imperfect state of chemistry, can hardly be determined by experiment; for what with the difficulty, or rather impossibility, of procuring bodies in a perfectly isolated form, and the unavoidable imperfections of all chemical processes; we can scarcely hope to approach within the necessary limits of precision.* If the above views of molecular relations,

* It seems to be now generally admitted by chemists that the atomic weights of hydrogen, carbon, oxygen, and azote, the four elements of

however, be well founded, it seems almost impossible to arrive at any other conclusion, than that the combining weights of all bodies are intimately related by multiple; though to enter further upou the subject here, would be quite foreign to our present purpose.

Finally, it may be remarked, that the numbers at present eonventionally employed by chemists, to represent what have been called the atomic weights of bodies, are so convenient, that they will not readily, nor indeed ought lightly to be set aside; though there is reason to believe that many of them require revision, and are destined to undergo material alterations, even as the subject is at present understood. If the views, however, which we have advanced be eorrect, these numbers certainly do not represent nature: for as we have already stated, a strictly philosophical arrangement can be rationally founded only upon the volumes of bodies in the gaseous state; in which state some common volume in all instances should be considered as the molecular unity. Now, seeing that in most instances this molecular unity appears eapable of subdivision, of course the number made to represeut such molecular uuity cau hardly ever be supposed to be a prime number. Henee, as combining molecules of bodies exist both below and above the moleeular unity, they often (perhaps always) may be represented by a series. Thus suppose 9 to represent the molecular unity, or volume, of water, and that this moleeular unity is subdivided into three (whieh it is at least, and probably into a mueh greater number); the molecular combinations of water may be represented by the series, 3, 6, 9̇, 12, 15, 18, &c. We mean to say, the molecules of water, as they actually enter into combination in different bodies, may be supposed to be represented by these numbers; while, by way of distiuctiou, moleeules below 9, may be designated generally sub-molecules; moleeules above 9, super-moleeules; and the molecular unity itself may be called simply the molecule; or in the gaseous state, the self-repulsive moleeule; distinetions, which, for the sake of eonvenience, we have adhered to throughout

which all organized bodies ehiefly consist, are 1, 6, 8, and 14, respectively. We shall reeur to this subject in the third Book.

the foregoing chapters, and which we have thought it thus necessary to explain.*

§ 3.—*Of Chemical Compounds in general.*

The number of chemical compounds is so great that an attempt to enumerate them here would be quite out of place: we shall therefore content ourselves with stating as briefly as possible the general principles, on which the laws detailed in the preceding section are supposed to control the formation of these compounds.

We have already described many of the more remarkable compounds when treating of simple bodies; and in subsequent parts of this volume we shall have occasion to allude to others. In treating of simple bodies, we showed that by far the greater number of them occur in the metallic state; and are incapable of existence upon the surface of our globe, on account of the tendency they possess to enter into combination, particularly with oxygen. It would seem also, from the intensity of the properties of the simple bodies, and their general incompatibility with the present order of things; that compounds, rather than simple bodies, were the objects the Author of nature had in view. Hence perhaps we are more immediately interested in the character of the compounds, than in that of the elements themselves.

The following observations, taken chiefly from Dr. Thomson's work on chemistry, will serve to convey to the general reader some idea of the nature of these compounds.†

The COMPOUNDS which simple bodies form with one another, are either PRIMARY or SECONDARY. By PRIMARY

* The above terms are to be considered as a temporary expedient only. If the views now offered be established, it will not perhaps be difficult to devise a corresponding notation and nomenclature. For some further remarks on these subjects, the reader who feels an interest in them is referred to the Appendix.

† Dr. Thomson's arrangement is so convenient for our purpose that we still adhere to it. This arrangement is doubtless open to many objections; but so are all other arrangements we have seen. A perfectly philosophical classification of chemical compounds is yet a desideratum, and we fear will long remain so. (Compare in regard to this point, Gmelin's Handb. der Chemie, Bd. 4.)—G.

COMPOUNDS, are usually understood those, which are formed by the combination of two or more simple bodies with each other; while by SECONDARY COMPOUNDS, are meant the compounds formed by the union of the primary compounds with each other.

The PRIMARY COMPOUNDS naturally divide themselves into three great classes; viz. acids; alkalies, or bases; and neutrals; each of which classes we shall consider separately.

Of Acids.—Formerly it was deemed requisite, that bodies, belonging to the class of acids, should have a sour taste, should be soluble in water, and should have the property of reddening vegetable blue colours; and these properties do indeed belong to some of the most common and powerful acids. But there are various acids which have no taste; which are not soluble in water; and some, which are incapable of altering the colour of the most delicate vegetable blues: hence the term acid, as at present employed by chemists, is understood to denote a substance which has the property of combining with, and neutralizing, alkalies or bases. The celebrated Lavoisier endeavoured to prove, that oxygen constitutes an essential ingredient of all the acids; but later observations have shown, as already stated, that not only oxygen, but also the analogous principles, chlorine, bromine, iodine, and fluorine, are capable of forming acids, by uniting with several of the acidifiable bases. Still more recently, certain primary compounds, as of cyanogen for instance, (a primary compound of carbon and azote), also of sulphur, of selenium, and of tellurium, with the acidifiable bases, have been ranked among the acids; so that the acids at present known, may be divided into at least nine classes, viz., oxygen acids, chlorine acids, bromine acids, iodine acids, fluorine acids, cyanogen acids, sulphur acids, selenium acids, and tellurium acids.

The oxygen acids are more numerous, and better understood, in general, than the other classes of acids: they may be subdivided into two kinds; those with a single base; and those with a compound base. The oxygen acids with a single base, amount to between thirty and forty, and include most of the best known and most important of the acids used in chemical processes, and in the arts; such as carbonic acid, sulphuric acid, phosphoric acid, nitric acid, &c. The

oxygen acids with a compound base are chiefly derived from the vegetable or animal kingdoms; they are still more numerous than the acids with a single base, the number at present known amounting to upwards of sixty; as instances may be mentioned the tartaric acid, the citric acid, the malic acid, the lithic acid, &c.

The chlorine acids are perhaps as numerous as the acids with a single base, containing oxygen; but they have been less studied, and are, consequently, much less understood. One of the most familiarly known belonging to this class, is the muriatic or hydrochloric acid; which is composed of chlorine, united with hydrogen: and here we may again point out the remarkable circumstance, before noticed, that not only chlorine, but all the other allied principles, when they combine with hydrogen, form powerful acids; while the compound of oxygen with hydrogen, is water; a substance altogether dissimilar. Such is the wonderful and inexplicable nature of chemical combinations!

The acids containing bromine, iodine, and fluorine, are still less satisfactorily known, than those containing chlorine. As just now observed, the acids formed by these different elements with hydrogen, viz. the hydrobromic, the hydriodic, and the hydrofluoric acids, possess the most decided properties, and are best understood.

The cyanogen acids are numerous and remarkable, as most of them are poisonous; thus the compound of cyanogen and hydrogen, (analogous to the compounds last mentioned,) is the hydrocyanic or prussic acid; one of the most virulent poisons in nature and instantly fatal to organic life in every form.

Of the remaining acids, the sulphur acids, the selenium acids, and the tellurium acids, we know very little. The acids from these bases with which we are at present best acquainted, are analogous to the preceding acids; and are formed by the union of sulphur, selenium, and tellurium. Those acids were formerly known under the names of sulphuretted, seleniuretted, and telluretted hydrogen; but some chemists have now given them new names, conformably to the nomenclature adopted for the acids, mentioned in the preceding paragraphs.

Of Alkalies and Bases.—Bodies of the class of alkalies,

are, as we have seen, like the acids, composed of different elements, and particularly of certain metals combined with oxygen, chlorine, &c., in less proportion for the most part than in the acids. Hence the alkaline bases are as numerous as the acids; and the alkalies may, in a similar manner, be divided into oxygen alkalies, chlorine alkalies, &c. Of all alkalies, the oxygen alkalies are by far the best known, and most interesting; and they may, like the oxygen acids, be subdivided into two kinds: viz. those with a single base, and those with a compound base. The oxygen alkalies with a single base, include all the well-known common alkaline bodies, potash, soda, lime, baryta, &c.; while the oxygen alkalies with a compound base, are chiefly from the vegetable kingdom; and comprehend the newly-discovered alkaline matters, so successfully introduced into medicine; such as quinine, from bark, morphine, from opium, &c.* Ammonia, or the volatile alkali, may perhaps be referred to this class of alkalies; though its composition, of hydrogen and azote only, without oxygen, may be considered as constituting an exception or anomaly.

The other alkaline bodies into which chlorine, iodine, &c. enter, are little known; and some, perhaps, may be even inclined to doubt their existence.†

Of neutral Compounds.—Neutral compounds are arranged by Dr. Thomson under seven heads, the mere naming of which, will probably be all that is required to convey to the general reader a sufficient notion of their nature. These compounds are water, spirits or alcohol, ether, ethal, (a peculiar oily substance obtained from spermaceti,) volatile oils, fixed oils, and bitumens.

Such is a condensed statement of PRIMARY COMPOUNDS, and of the principles on which they have been arranged. We come now to consider briefly,

The SECONDARY COMPOUNDS; or the compounds formed by the union of the primary compounds. As the neutral

* We are aware that the composition of these and the other organic alkalies has been viewed in a different light; and perhaps the composition stated does not represent their exact nature, which seems to be yet unknown.

† The last few years have however greatly advanced the knowledge of these compounds; see Gmelin, Handb. der Chem.—(G.)

primary compounds, (if we except water,) enter into few combinations, it is obvious that the SECONDARY COMPOUNDS must consist chiefly of substances formed by the union of the other two general classes of bodies; namely, of acids and alkalies. These SECONDARY COMPOUNDS are usually denominated SALTS; they constitute a very numerous and most important class of bodies; and, as resulting from the mutual union, and saturation, of all the different principles capable of combining with each other, they of course are more abundant than any other bodies; indeed, the surface of our globe may, in a great measure, be considered as made up of secondary compounds. The term salt was originally confined to common salt; but by a singular fate, this body, because it is composed merely of chlorine and sodium, is now excluded from the class of salts: salts being, as we have just now said, considered by chemists, to be formed, only, by the union of acids and alkalies.* As there are nine classes of acids, there must consequently be as many classes of salts; of these, the oxygen acid salts are by far the best known, and the most valuable; and, indeed, this class includes the greater number of those salts employed by chemists, or in the arts. If the salts be arranged according to their bases, which perhaps on the whole, in the present state of our knowledge, is the best mode of arranging them, they will be found to constitute upwards of fifty genera; and if we consider that each of these genera includes, in most cases, a great number of species; we may form some idea of the wonderful variety of compound substances existing in nature; and with the properties of which the chemist is required to be conversant. Familiar instances of the oxygen acid salts are, nitre, common chalk, gypsum; various metallic salts, as the white, green, and blue vitriols, &c. &c.

Of the chlorine, and the other classes of salts, very little is known, and this little is chiefly confined to the salts composed of these elements with hydrogen. The hydrochloric or muriatic acid combines with ammonia, and forms the familiar compound sal-ammoniac, a salt supposed to be a true hydrochlorate, or muriate. But this is almost the only case existing; and in analogous substances, the hydro-

* This limited view of the nature of salts, is not now adopted. See Gmelin's work, previously quoted (p. 112, note).—(G.)

gen of the hydrochloric acid, and the oxygen of the base, unite to form water, which is generally separated, or separable; and thus the chlorine and the metallic base are left in union by themselves, in the state of a chloride. Such is the case, for instance, with common salt; which, as we before said, is in reality a chloride of sodium; that is to say, a simple compound of chlorine and the metal sodium. Similar remarks appear to be applicable to the most of the other analogous compounds.

What has now been said will serve to convey to ordinary readers a general notion of chemical combinations. In the present work, more cannot be attempted; and those who wish for further information are referred to treatises professedly written on chemical subjects.

§ 4.—*Of the motions of imponderable and ponderable Molecules; with some conjectures on the nature and relations of Homogeneous and Heterogeneous Phenomena.*

We have reserved for this place a few remarks on the extent and velocity of molecular motions; as well as some conjectures on the relations of molecular phenomena to one another.

The motions of imponderable and ponderable molecules may be considered under two heads: viz. the distance moved by, and the velocity of motion of individual molecules; and the distance moved by, and the velocity of motion of aggregated molecules.

As an instance of the minute space moved over by individual molecules (or undulæ) and the extreme velocity of their motions, we may briefly notice the molecular motions producing the phenomena of light. And here it may be remarked that the spaces and velocities we shall state have a real existence, and were deduced by Newton from actual admeasurements. They involve, therefore, nothing hypothetical but the names assigned to them by different philosophers; and consequently are not affected by any theory of light we may choose to adopt: in other words, if we adopt Newton's theory of light, the spaces and numbers to be stated denote the distances between the alternate presentations of the two poles of the molecules of which Newton

supposed light to consist, and the number of times in a second these poles are alternately presented in the same direction. Or if we adopt the undulatory theory of light, the spaces and numbers mentioned denote the length or distance of each undula or wave in advance of the preceding wave; and the number of times in a second which it vibrates at right angles to the direction of the ray.

The number of molecular motions in a given time, as well as the space the molecules travelled over, were found by Newton to vary with the colour of the light. In the extreme red ray of the solar spectrum the extent of each molecular motion was ·0000266 inch, and the number of such motions in a second were 458 millions of millions; while in the extreme violet of the solar spectrum the extent of each molecular motion was ·0000167 inch; and the number of such motions in a second were no less than 727 millions of millions. In the intermediate colours of the spectrum, the distances and numbers lay between these two extremes. Of such distances and numbers we can form no conception; yet minute as they are, we cannot doubt that the distances stated represent the virtual influences of the moving molecules, rather than the real magnitude of the molecules themselves; *i. e.* the real magnitude of the molecules must bear the same relation to the spaces they travel over, as the ball of a pendulum bears to its arc of vibration; or as the molecules of water in an aqueous wave bear to the distance between two consecutive waves.

Among other instances of the wonderful relations of molecular phenomena to space and time, we may notice the phenomena of chemical combination and separation. To the molecular operations of chemistry we cannot indeed apply actual admeasurement, as in the instance of light; but the following brief recapitulation may serve to convey a faint idea of their general nature, and of their wonderful character.

We have seen that the minutest particle of matter consists of myriads of molecules; that each of these molecules, besides certain properties in common, possesses likewise certain properties peculiar to the original particle of matter; that these peculiar properties of different molecules determine their absolute and bodily union with, or separation

from, other molecules; that all these countless unions and separations take place without the least confusion, and with a precision precluding error, in a space, and in a time, not only too minute to be estimated, but even conceived. We have dwelt on all these and other things equally wonderful; and in restating them here we purposely make one more attempt to convey an idea of the inscrutable relations, the phenomena incessantly going on within and around us, and necessary not only to our own existence, but to the existence of the universe, bear to time and space.

As an instance of the distance moved, and the velocity of motion of numerous aggregated molecules, we shall again select light for illustration.

Light radiates or moves in straight lines with such astonishing velocity, that it occupies only about eight minutes in travelling from the sun to the earth; so that it must move at the rate of nearly 200,000 miles in a second! At the same rate, light would occupy about four hours to travel to us from the planet Uranus, the present *ultima Thule* of our system;* hence if this planet were at any given instant suddenly annihilated, we should not miss it for four hours afterwards; and when we look at the planet we do not see it where it actually is at this instant, but where it was four hours previously. A cannon-ball when first shot from the cannon moves with a velocity of between 2,000 and 3,000 feet per second; supposing therefore the cannon-ball could retain its initial velocity, it would scarcely move in a year, as far as light moves in a second! The utmost velocities of the earth and other planets in their orbits or on their axes, scarcely exceed 30 or 40 miles in a second. Hence the utmost velocity we are acquainted with, as possessed by ordinary matter, and therefore the utmost perhaps of which ponderable matter is capable, amounts to only the 1-5000th or 1-6000th of the velocity of light.

The exact velocity of the other imponderable bodies, as of radiant heat, electricity, &c., is not known. In the preceding remarks we have followed the usual opinion, and considered the velocity of heat to be similar to that of

* The orbit of the more recently discovered planet Neptune, is beyond that of Uranus.—(G.)

light. The velocity of the electric fluid has been supposed to be fully equal to, if not greater than, the velocity of light.

These striking facts are mentioned not only with the view of conveying some notion of the wonderful velocity with which space is in every direction penetrated by light and heat, but of the immensity of space. These facts seem also to show that the matter of which light and heat are composed must exist in a state of tenuity totally different from that of ponderable matter, which actually seems incapable of such velocity.*

It may be proper to mention that the distances travelled over by imponderable molecules are solely due to the incessant flow of numerous molecules or waves, which from their intense state of mutual repulsion, urge on one another with the velocity above stated. We have described the motions of individual molecules or waves in a previous paragraph; and we may here remark that a single pair of molecules, or a single undulatory impulse, however intense their initial repulsive energy, would not probably travel beyond a very small distance.

In the brief survey now to be taken of the general nature and relations of molecular phenomena, after noticing some of the opinions at present entertained on these subjects, we shall attempt to point out a few of the more obvious analogies and relations existing among these phenomena, in the different orders of imponderable and ponderable molecules.

Of the intimate nature of light and heat, electricity and magnetism, homogeneous and heterogeneous attraction and repulsion, and of their relations to each other, we have already confessed our comparative ignorance. Nor has any hypothesis or theory been yet framed sufficiently comprehensive to include all the phenomena of these different branches of knowledge, so as to give them consistency, and to explain their analogies and relations. The undulatory theory of light, and the molecular theory of Mossotti, as formerly mentioned, include certain groups of phenomena only, and are quite inapplicable to others. The phenomena

* Pouillet, Elémens de Physique et de Météorologie, tom. ii. p. 216.

of light and heat, for instance, cannot be explained by Mossotti's theory: nor is the undulatory theory of light and heat applicable to the phenomena of electricity and magnetism, much less of chemistry. The necessary conclusion is, that these theories are imperfect at the least, and that their adoption, by circumscribing our powers of investigation, or by misdirecting them, is more likely to retard than to assist the progress of discovery.

Of the relations of Light and Heat.—Light and heat are so associated that when the one exists in certain intensity we usually expect to find the other. This constant association of light and heat have long since led to the notion that they are in some way related; and a further inquiry into their phenomena, not only strengthens this opinion, but seems to point to the nature of the relationship between light and heat.

If we judge of light and heat by their effects, heat appears to be by far the most energetic of the two agencies. The energies of heat also are of a remarkably divellent character, and are exerted in expanding, separating, and dispersing bodies. On the other hand, the energies of light have no such striking divellent effects. Indeed, apart from the heat which usually, perhaps always, accompanies it, light is scarcely known to exert divellent force of any kind. On the contrary, light appears rather to favour the union of bodies than their separation. Plants for instance, as well as other organic bodies, grow, and become increased in bulk under the influence of light; and even many inorganic bodies, so far from being destroyed by light, as they would by heat, have their properties exalted by solar influence. We admit that in many of these cases it is difficult to state how much is due to light, and how much to heat, yet the broad fact for which alone we at present contend, that heat in general exerts divellent energy, while light does not, can scarcely be called in question.

Of the relations of Electricity and Magnetism.—When treating of electricity and magnetism in a former chapter, we pointed out the mutual relations of their energies. We showed, in fact, that if electricity be considered to move axially, magnetism in every instance circulates equatorially or centrifugally round such axial motion. As compared

with one another, the axial or electrical energies apparently far surpass in intensity the equatorial or magnetic energies; which have more of a secondary or resultant character, than the axial or electrical motions.

Of the relations of heterogeneous and homogeneous Forces to Electricity and Magnetism, and to each other.—We have already alluded to the opinion now generally entertained among chemists, that the electrical energies are the cause of chemical phenomena; and we at the same time stated, that instead of bearing the relation of cause and effect, the phenomena of electricity and chemistry appear rather to be only different expressions for the same thing. We shall now resume this question.

The terms cause and effect usually imply priority and subordinacy; *i. e.* the cause precedes, or at the utmost moves *pari passu,* but never can be preceded by, or substituted for, the effect. Now, if we apply this rule to electrical and chemical phenomena, we find that electrical phenomena produce chemical changes; and *vice versâ*, chemical changes produce electrical phenomena—facts apparently precluding the notion of cause and effect between these two orders of phenomena; and rather showing, as we have just stated, that electrical and chemical phenomena are only different expressions for the same thing; in other words, that the phenomena of electricity and of heterogeneity are identical. But it will be asked, if electricity represents or is identical with heterogeneity, what does magnetism, the necessarily concomitant of electricity, represent? There seems to be but one answer to this question, viz., that the phenomena of magnetism represent, or are identical with, the phenomena of homogeneity. This conclusion, not at first, perhaps, very apparent, demands a brief consideration.

On reverting to Fig. 6 and Fig. 7, (page 60,) it will be found that when two currents of electricity are made to pass through two contiguous wires, no matter of what metal, the two wires will attract or repel each other according as the two currents of electricity move in the same, or in opposite directions; exactly as two magnets would do under similar circumstances. These facts show that the magnetic energies are general, and independent of iron, which possesses only the peculiarity of retaining and displaying their phenomena.

The establishment of the general and independent characters of the magnetic energies, removes a great obstacle to the opinion we are now endeavouring to illustrate; viz. that the energies of homogeneity and of magnetism are identical.

The various figures of molecules formerly given, (page 66,) may be again referred to for illustration. We must now however consider these molecules in motion, and the axes E *e* E *e* of two contiguous molecules, to convey electric currents, like the two wires, in the arrangement described. (page 60.) In this case, the points M *m* M *m* on the molecules will represent the equatorial or magnetic currents. Now, on such a supposition, if the electrical, chemical, and heterogeneous energies be identical, the magnetic and homogeneous energies must be also identical; and the only way in which two molecules can combine chemically, is at the extremities of their axes; in other words, at their poles; while two molecules can combine magnetically (*i. e.* homogeneously) at every other point of their superficies, as well as at their equators. With regard to the causes of homogeneous and heterogeneous union, they are probably to be sought for in the similarity and dissimilarity of the motions of different molecules. Under favourable circumstances, similar molecules all moving alike, may be supposed to combine in any appropriate points determined by the figure of the molecule; while dissimilar molecules, moving differently, may be supposed to be able to effect a combination only at those points, where the motions of the molecules are the least possible, namely, at their poles.

The nature of this work precludes further enlargement, but what has been stated we may briefly recapitulate in a connected form.

The reader will bear in mind that the forces of gravitation, attraction and the resultant force which resists attraction, act as if they were associated, and resided in every individual atom of matter in the universe; hence every atom mutually attracts, and is attracted by every other atom. The polarizing forces, on the other hand, are evidently dissociated, and reside in different parts of the same molecule or mass; hence this molecule or mass, can in no instance

be a mathematical point, (or atom ?) but must consist of at least two parts: hence also as all matter appears to possess polarity, matter must exist in the state of molecule; each of which molecules must occupy actual space.

Such are the differences between the forces of gravitation and the forces of polarization; which after all are more apparent than real: the forces of polarization being merely the forces of gravitation modified by the molecular condition of matter. We mentioned formerly that the attractive force of gravitation, as we are acquainted with it, appears to represent only the excess of the amount of the centripetal over the amount of the resultant centrifugal force in nature; and the conclusion is, that the attractive force taken *per se* and as it really exists, must be infinitely greater than the apparent force of gravitation—indeed so great, that if not prevented by the opposing centrifugal force, the whole of the matter in the universe would instantaneously rush together into one mass. Further, as the resultant centrifugal force of molecules in motion on their axes, is the least possible, or 0, at their poles; the smaller the molecules, the larger the ratio the quiescent poles, bear to the superficies of the molecules. It follows, therefore, that both the attractive polar force, and the resultant centrifugal force will increase in intensity as the molecules diminish in magnitude—facts which appear to account for the greater intensities of action of imponderable molecules.

From what has been said, the reader will doubtless anticipate the following conclusions, which we subjoin as briefly as possible.

First. That the phenomena of light, of electricity, and of heterogeneity, (admitted to be the same as the phenomena of chemistry,) are identical in their character, and have reference only to the polar attractive force of molecules.

Secondly. That the phenomena of heat, of magnetism, and of homogeneity, (*i. e.* of cohesion and divulsion,) are identical in their character, and have reference only to the resultant centrifugal force of molecules.

Thirdly. That the apparent differences between the phenomena of light, electricity, and chemistry; and the phenomena

of heat, magnetism, and cohesion; depend on the differences in magnitude and consequent different intensities of action among molecules. That the imponderable molecules, from their minuteness and the intensity with which they act, pervade every form of aggregation assumed by ponderable molecules, and influence (*i. e.* exalt or depress, as the case may be,) the natural motions of these ponderable molecules; and that thus imponderable molecules assume the character of subordinate agents.

Fourthly. That the phenomena of electricity and galvanism (and consequently the phenomena of chemistry) depend on the operations of ponderable molecules of different magnitudes and intensities of action. That the phenomena of electricity, in general, result from the operations of a more minute, and consequently more intense, order of molecules than the phenomena of galvanism, such as the sub-molecules of which we formerly showed primary elementary molecules to consist: while galvanic phenomena, though partly depending on the more intense order of molecules mentioned, result chiefly from the operations of the common molecules of the primary elements. The same remarks apply in a certain extent to the co-ordinate phenomena of magnetism and homogeneity.

Fifthly. That the attractive energies of light, electricity, and heterogeneity are one and the same; and are all identical with the attractive force of gravitation. That the resultant repulsive energies of heat, magnetism, and homogeneity, are one and the same; and are all identical with the centrifugal force of gravitation. That the apparent polarities of light and heat, electricity and magnetism, depend on the various coincidences and interferences of molecular motions with one another. And lastly, that the attractive phenomena of heterogeneity and homogeneity are regulated, modified, or suspended, chiefly by the degree or absence, of the resultant centrifugal forces of the imponderable molecules producing heat.

The foregoing attempt to connect physical molecular phenomena is acknowledged to be very imperfect. Enough, however, has been said to draw the attention of those who are interested in the subject. Another age will follow out these or some nearly allied principles; and the physical

phenomena of the microcosm will thus become as much a matter of mathematical inquiry and proof, as the physical phenomena of the macrocosm or universe now are.

Ch. X.—General reflections and arguments on the subjects treated of in the preceding chapters.

We shall now conclude the present Treatise on Chemistry, with a few remarks, more especially relating to the object of these publications. And here it may be observed, once for all, that throughout the preceding pages, as well as in what follows, we have endeavoured to state each argument as distinctly as possible, without encumbering it too much with details—in short to illustrate principles, rather than to enumerate particulars. When the principles of a cumulative argument are understood, the details are readily supplied by the reader.

First. On taking a general and collective review of the facts brought forward in this Treatise; the circumstances calculated to strike our attention in the first place, are the wonderful coincidence between the priority of existence, and the universal prevalence, of the primordial agents and elements of nature, on the one hand; and on the other hand, the beautiful adaptation of the agents and elements of a later, and more subordinate character, to these primordial agents and elements; so that, when the whole are taken together, they constitute one harmonious and connected series, in which all the various parts are mutually adapted, and dependent. In the other Treatises, we shall have occasion to notice many of the more important of these subordinate arrangements; at present, we shall chiefly confine ourselves to a general review of what has been detailed under the head of Chemistry.

We are told by the inspired historian, that when matter had been created, and endowed with motion, the next Almighty fiat was, "let there be light;" and if we suppose this fiat to have included tho other imponderable form of

matter, heat, how entirely do the whole phenomena of nature accord with the sacred narrative? Light, and probably its attendant heat, are the most generally diffused and universal of all the subordinate agencies; so much so, that they are not confined to our globe, or even system, but extend throughout the universe. The laws and influences, therefore, of light and heat, seem to be as general, and as necessary to the present order of things, as the laws and influences of gravitation itself. The priority of existence also, of light and of heat, is self-evident; for until light and heat existed, nothing else, as we are acquainted with things, could have had existence. Now, all subsequent creations have been called forth with the most exact regard to the influences of these prior agencies. The globe, for example, which we inhabit, is placed at a certain distance from the sun, the great centre of our system, and of light, and of heat; and where of course, according to the laws which light and heat obey, these agencies must act with a certain intensity. Hence it was necessary that the materials of our globe should have a certain degree of fixity; otherwise they could not exist. If, indeed, there had been no ulterior views, with respect to the destination of our globe; all that would have been requisite, would have been, to have made the globe sufficiently firm to move through space; and for this purpose, the more homogeneous and compact its composition had been, the better. But what are the facts? Our globe, though stable; so far from being homogeneous, is composed of a variety of substances, all differing from each other in their properties; some being solid, some fluid, some aeriform, under the common circumstances in which they have been placed; and all beautifully adapted, both by their physical and chemical properties, to the purposes they fulfil in nature; nay, what is more, to the purposes they were designed to fulfil in nature; for on no other supposition, would the properties of these various substances be intelligible.

Thus water, within very narrow limits of temperature, is a solid, or a liquid, or a gas; and yet these very narrow limits of temperature, neither more nor less, are precisely the limits which exist upon the surface of our globe; where they are the natural, and the necessary results of its situa-

tion in the universe; and of the general laws which govern the distribution of light and heat. Had the properties of water been other than they are; or had the general temperature of our globe been different; water would have existed altogether in the solid, or in the gaseous state; and its most important properties would have been unknown. Hence, it seems almost impossible to arrive at any other conclusion, than that the temperature of the earth, and the properties of the water on its surface, have been mutually adjusted to each other. And further, since the temperature of the earth, as above stated, is the natural result of the general laws which govern the distribution of heat and of light; the inference must be, that the properties of the water, as the subordinate and later creation, have at an after period, been adjusted to the prior temperature of the earth.

If we do not admit of this adjustment, we must suppose that the whole has been the result of chance, or of some other unintelligent principle; and if water had been the only case in which such adaptations were apparent, the supposition of chance might, perhaps, be received; at least it would be difficult to prove the contrary. But when we see similar happy adjustments in every object around us,—in the different elements of the air we breathe, in the soil we tread upon, in all the varieties of rocks composing the solid crust of our globe; not one of which could have been more happily contrived for the purposes they fulfil, nor indeed be scarcely conceived to exist otherwise than as they are, without destruction to the whole of the present arrangements—when we see all these things, and duly reflect on them; it becomes absolutely impossible to suppose, that so much happy adjustment; so much apparent intelligence; so much, in short, of what the veriest sceptic, under other circumstances, would have allowed to be evidences of design, can be evidences of any thing else than design; or have resulted from any unintelligent cause whatever. Hence we are irresistibly impelled to the only rational conclusions the premises appear to admit of, viz.; that all these happy adjustments, and adaptations, which we see in nature, are really and truly what they appear to be,—so many evidences of design; and, consequently, that the

whole have sprung from the will of an intelligent, and omnipotent Creator.

These inferences are deducible from the plain and obvious arrangements of nature, which every one can readily understand: but when treating of elementary bodies, we remarked that, in a variety of instances, their object and use were unknown to us; and before we quit this part of our inquiry, it may not be out of place to consider briefly these difficult points.

When we see adjustments so wonderful, and such wisdom displayed in those parts of creation which are intelligible to us; we cannot imagine that a Being who made them all, would act otherwise than with wisdom. Hence, what we do not understand, or what may appear incongruous to us, we naturally and properly refer to our own ignorance. The phenomena of chemistry are so extraordinary and often so unexpected, that little in general can be predicated of them, beyond what is actually known. The most experienced chemist, therefore, as compared with the Great Chemist of nature, is immeasurably deficient; and can only contemplate His wonderful operations with astonishment and awe, and own them unapproachable. Who then can tell what design is latent under apparent incongruities? What elaborate contrivances, and adaptations, may have been requisite to have produced water, or carbon, or any other constituent of our globe, out of the materials, and in conformity with the laws, by means of which the Great Author of nature chose to operate? Who can tell that the minor evil may not have been indispensable to the existence of the greater good? That the poisonous metals, for instance, are not, as it were, the refuse of the great chemical processes, by which the more necessary and important elements of nature have been eliminated? That these poisonous matters have not been left with such subdued properties, as scarcely to interfere with His great design,—not because they could not have been prevented—not because they could not have been removed—but on purpose, and designedly, to display His power?

Secondly. If we pursue the subject a step further, and inquire into the means by which all the beautiful adaptations we have been considering, are effected; we shall find, that

they chiefly depend upon a certain due adjustment, to each other, of the qualities and quantities of the different substances; and more especially of the different elementary substances of which our globe is composed. These adjustments are so universal, and so varied in their character; that to enumerate them all, would be little else than to enumerate all the objects in nature; we shall therefore content ourselves with a few of the most familiar of each kind.

In the first place, with respect to the adjustment of quality. Let us consider for a moment, and by way of illustration, what would happen, if the qualities of water, or of air, were to undergo a change: were, for example, the important fluid water to become sour or sweet; or heavier or lighter; or indeed anything but what it is: or were the air of the atmosphere to acquire odour or colour; or to become opaque: by either of such changes, slight as they appear, the whole of the present economy of nature would be deranged. Again, if the qualities of the acid existing in the common salt of the ocean, were to become so modified, as to quit the alkali with which it is at present associated, and combine with the limestone composing our rocks; while the carbonic acid, thus set free, was diffused through the atmosphere: in such a case, a large part of the solid crust of our globe would rapidly disappear, and becoming dissolved in the waters of the ocean, would altogether destroy their present condition; while the liberated carbonic acid, would instantly prove fatal to animal life. These would be the consequences of changes so trifling, in the qualities of a few substances only; nor is it possible, scarcely, to conceive any other change, that would not be attended with similar results.

In the next place, the importance of the adjustments of quantity, is equally striking. Let us, for instance, conceive what would happen from the simple inversion of the quantities of dry land, and of sea, as they now exist: in such a case there would not be enough of water to preserve the surface of the land in a moist state; the greater part of the land would thus be in the condition of the deserts of Africa; and totally unfitted for the habitation of organized beings. When treating of the elements of water, we alluded to the happy adjustment of the quantities of oxygen and of hydro-

gen in the world; and to the consequences which would have ensued, if hydrogen instead of oxygen, had predominated. The same remarks apply to almost every other element; for example, had the proportions of the chlorine, and of the soda in common salt; or of the carbonic acid, and of the lime, in our marbles, been different from what they are; the one or the other of the ingredients must have been in excess; and the present order of things could never have existed. Again, were gold suddenly to become as abundant as iron, and iron as rare as gold; were the carbon existing in the present useful form of fossil coals, to assume the crystallized form, and become diamonds; the whole order of nature would be subverted, and the whole of the present arrangements be involved in ruin. Those who deny the argument of design, of course consider such suppositions as these absurd; and if carried too far, they doubtless, under any circumstances, lose much of their effect; but admitting the argument of design, the judicious application of such suppositions, is well calculated to place the advantages, and effects, of certain arrangements in a more striking point of view than can be obtained by any other means. More especially, such suppositions, by showing the wonderful adaptations of subsequent creations to prior existences, are admirably calculated to illustrate the fitness, and consequently the apparent design, displayed in the formation of the prior existences; and thus to show, that these prior existences must have been created with reference to ulterior purposes.

The argument of prior arrangements, and of the subsequent adaptation of other creations to these arrangements,, is one of such interest; its consequences, also, are so important; that perhaps it may not be deemed irrelevant, if, for further illustration, we recapitulate the argument in a condensed form. For this purpose, we shall select the obvious and familiar relation of plants and animals to water and air.

The prior existence of water and air, as compared with the existence of plants and animals, is established by the fact, that water and air can exist without plants and animals; but that plants and animals cannot exist without water and air. Hence, as water and air must have existed, with all their present properties, before plants and animals

were created; the question naturally arises, how water and air came to be endowed with their present properties? We suppose that water and air were created with their present properties, with reference to the future existence of plants and animals; and on this supposition the whole becomes intelligible. Further, that this is the true explanation, and that water and air have not obtained their present properties, by chance, or accident, is rendered still more probable by the following considerations. We have said that water and air can exist without plants and animals: now as far as we know, water and air might have existed for ever without plants and animals; at least the contrary cannot be proved, or even rendered probable. Moreover, plants and animals, as involving new agencies of a higher order, (the agencies of life,) never could, by any law of nature, necessary or probable, have resulted from an inferior agency. Hence, there is no necessary relation of cause and effect, between the prior existence of water and air, and the subsequent existence of plants and animals, as some seem to have supposed. Hence too it follows irresistibly, that plants and animals have been created, and their properties adapted to the properties of water and of air, at some subsequent period, and by some external and superior agent. But the agent that could thus create plants and animals, could surely have created the water and air likewise; nay, must have created them; for, as the prior and subsequent creations taken together, evidently form but different parts of one and the same general design, the whole design must have been the work of one and the same intelligent Agent.

It yet remains to draw the attention of the reader to another circumstance, connected with the adjustments in quality and quantity, viz. the double adjustment. Of the causes of the qualities of bodies we know but little, and that little is founded solely on experience. We see that these qualities are admirably fitted for their apparent purposes; and hence, as the qualities might have been different, we arrive at the probable conclusion, that they have been so fitted by design. The collocation of qualities and numbers, exactly where they have been required, adds much to the probability of this conclusion; because such a collocation could hardly have been other than the act of an intelligent

Being. But the double adjustment in quality and quantity, of the same thing at the same time, adds almost infinitely to the weight of evidence; and indeed furnishes a proof in favour of design, and of its consequences, which amounts to all but actual demonstration.

Thirdly. There is another mode in which we may view the arrangements of creation, and by which we shall at the same time, be brought a step nearer to the existing order of things. Amidst all that endless diversity of property, and all the changes constantly going on in the world around us, we cannot avoid being struck with the general tendency of the whole, to a state of repose, or equilibrium. Moreover, this tendency to equilibrium is not confined to the ponderable elements, but prevails also, in the same remarkable degree, among the imponderable agencies, Heat and Light; which, as we have seen, cannot be anywhere long retained in a state of excess, on account of their natural disposition to acquire a certain state of equilibrium; depending generally upon the place of the earth in the solar system. Now, the formation of this state of equilibrium, and its preservation, may be considered as the results of those wonderful adjustments among the qualities and quantities of bodies above alluded to; the qualities being such as to neutralize each other's activity; while the quantities are so apportioned, as to leave one or two only, predominant.

Having premised this general view of the objects of nature, it is to be further observed, that their state of equilibrium is not absolutely fixed: such an unyielding condition would be not less incompatible with the present order of things, than a condition of unlimited change. All things, therefore, are so adjusted, that slight deviations, or oscillations about the neutral point of rest or equilibrium, take place, and are even necessary, as the world is at present constituted; though these changes are bounded within very narrow limits, and greater deviations would instantly prove fatal to the whole. If we inquire into the principles on which these slight deviations take place, and are regulated; we shall find still further reason to admire the wonderful arrangements displayed. When speaking of the elements of water, we observed how much the sta-

bility of nature depended on the proportions of the elements of this fluid; and that one of its elements, oxygen, existed in excess, and in a free state, in the air. Now, to the agency of this oxygen in a free state, and to the annual and diurnal motions of the earth, most of the minor operations going on around us are to be referred. The universal presence, and peculiar properties, of oxygen are such, as to interfero more or less, with every thing: while the motions of the earth keep every thing in a constant state of activity and change. Yet, the general tendency of the whole, as before observed, is toward a state of equilibrium, and the principles on which this tendency operates, are very intelligible. Thus, all bodies below the neutral point of rest, if we may be allowed the expression; that is to say, all bodies of a marked elementary character, have a tendency to combine with each other synthetically; while beyond the neutral point, bodies have very little tendency to combine further; and if by intention on the part of the operator, or from any other cause, they be made so to combine; when left to their own operations, they speedily revert, or oscillate back, to the point of equilibrium.

Such are the means by which the state of equilibrium we are considering has been produced, and by which it is still preserved; nor is it possible to reflect on them for a moment, without arriving at the conclusion, that this state of equilibrium possesses all the characters of a prior arrangement, to which organized beings have been subsequently adapted. We are thus led, in the course of our argument, to consider the adaptation of organized beings to the pre-established equilibrium of nature.

The present races of organized beings, are, in all instances continued only by the process of generation; and if they were annihilated, there are no natural operations going on in the world, which can lead us to believe, that by any law of nature, such organized beings could be reproduced. That is to say, we cannot conceive that hydrogen, carbon, oxygen, and azote, with heat and light, &c., from what we know of their properties, would ever be able, of their own accord, so to combine as to form a plant or an animal. Hence, when plants and animals were first produced, it is evident that there must have been a power or agent in

operation, which has long since discontinued so to operate; and that this power or agent not only created plants and animals; but at the same time imparted to them a capability of perpetuating their existence, for a period, at least, commensurate with that state of equilibrium in which they have been placed. Now, whether we consider the power or agent who accomplished these things, to have been the Deity himself operating immediately, which is most probable; or whether we consider with some, that He operated by delegated agencies and laws, the result is the same as far as our argument is concerned; the object of which argument is to show, that the present races of organized beings are, somehow or other, influenced by the same general laws, which appear to regulate inorganic matters. That is to say; organized beings at the present time, are at least as fixed and permanent in their nature, as the state of equilibrium in which they have been placed; and consequently, no new plants or new animals, can, as the world now exists, be imagined to be produced, without a new and specific act of creation; or at least, without an entire change in the standard of equilibrium.

We have alluded to the commencement of the present order of things, and to a possible state of change in the condition of equilibrium: let us pause on these momentous questions.

That the present order of things, most certainly has had a beginning: and as certainly, will come to an end; we cannot doubt: the questions are, when was this beginning; when will be this end? Of the end, we can know nothing: the beginning is less obscure; and there are indelible impressions left upon the materials and structure of our globe, which throw no ordinary light on this question. The consideration of the changes which our earth has undergone, however, belongs to another department: we shall only observe, that these changes appear to be of two distinct orders; which have alternated with one another in succession. The first of these orders of changes, seems to have been of a slow and gradual kind; and such as might be supposed to take place, during a state of things, more or less like the present, and existing for a considerable period. The changes of the second order, on

the contrary, have evidently been violent, sudden, and disruptive; of comparatively short duration, and differing exceedingly in degree, and in extent. In general, disruptive changes appear to have operated from within; but whether altogether from internal, or from external influences, is unknown to us. Now, it is remarkable, that these successive alterations seem each time to have changed the standard of equilibrium; and that during the state of comparative quietude, or the interval of equilibrium between the convulsions, organized beings have existed, adapted to the exigencies of that particular state of equilibrium; and which beings must have been successively created: moreover, the later creations gradually approach to those at present in existence. Hence, not only does the change in the standard of organization seem to have been simultaneous with the change in the state of equilibrium; but both appear to have been progressively raised after each convulsion. Finally, the last general catastrophe of the disruptive order was evidently a deluge.* Such are the conclusions, which geologists have deduced from a careful survey of that part of the crust of the earth to which they have access; and these conclusions are of the most important kind. In particular, by demonstrating the existence of successive adaptations, to successive and different states of equilibrium; they place the argument of design in a new light, and add, in no small degree, to its force. This part of the subject, however, belongs to the geologist, to whom, for the present, we shall leave it.

Fourthly. The argument of design, as connected with the state of equilibrium in which we live, may be considered

* If we judge from what is going on around us in nature, and from the little tendency there appears to be in things at present, to combine into new forms; we must be almost led to the conclusion, that the developement of new elements, as well as of new agents, is necessary to produce new and specific arrangements. May we not then infer, that during those periodic convulsions alluded to in the text, new elements have been developed, or old ones decomposed into others of a higher, and more elementary kind; and that in virtue of the general laws in operation, these new elements have subsequently combined to form series of new arrangements? Of course, this supposition is intended to apply only to the means adopted by the Deity to effect His purpose. The formation, and selection of these new elements, must, in all instances, be supposed to result immediately from His will and agency.

yet in another manner. In this state of equilibrium, we have observed, the properties of bodies, as they actually exist around us, are all so subdued and passive in their character, that no one predominates over, or excludes the others. Now, when we reflect that almost all these bodies are compounds; and when we compare the properties of such compounds, with the properties of the elements composing them; it is impossible not to infer, that the properties of the compounds, rather than the properties of the elements, were, at their origin, the objects contemplated. That is to say; in order that the compounds might be perfect, the elements calculated to produce them, were created essentially such, as these compounds might require; without reference to the secondary properties of the elements themselves; which were left to be determined, as the more general laws of matter might decide. For instance, the hydrogen in water, and the chlorine and sodium in common salt, not being, in their simple state, required in the economy of nature; the properties of these elements have not been made compatible with organic existence; and the whole attention, (if such a term may be applied to the operations of the Deity,) has been directed to the properties of the compounds, water, and salt. Thus, on the one hand, where required, we have the most striking adaptation of property; while on the other, where not required, this adaptation of property has not been regarded: nor is this true of water and salt only, but of almost every other compound in nature. Nay, what is more, the incongruities of the whole system have, with the most consummate skill, been thrown, as it were, among those properties not required. Hence, the arrangements of nature viewed in this light, not only exhibit novel evidences, but some of the most striking evidences of design, which we possess.

The subject of the incongruous properties of bodies, is one of great interest. We have seen that many of the primary elements are poisonous; and that almost all of them, if liberated from their affinities, and sent abroad in the world like so many demons let loose, would instantly bring destruction upon the whole fabric. Now, why should such incompatible properties be necessary to the properties of the compounds? Why, for instance, should the incom-

bustible fluid, water, contain one of the most combustible principles in nature? Or the mild and innocuous common salt, be composed of two elements, which, in their separate state, would instantly destroy life? Why, we repeat, are these deleterious properties of the elements necessary to the wholesome condition of the compound? What part do they perform; or what property do they represent, or modify? These are questions utterly beyond our comprehension; and are likely always to remain so. That these incompatible properties of the elements, however, do, in some way, contribute to the perfection of the compounds, we cannot doubt; and the only grounds, on which such incompatibility seems to admit of explanation, is; that it results necessarily from those limitations, which the Deity has thought proper to prescribe to His power; and to which He always most rigidly adheres. Moreover, be the reason what it may; it is evident that these arrangements, so immediately calculated to lead to practical difficulties, have been the result of Choice. For we cannot but believe that an omnipotent Creator, if He had so willed, could have made the elements innocuous, as well as the compounds; nay, to our limited understanding, this would have been the easiest, and most natural mode of proceeding. Why then did He choose the apparently more difficult course? Why, to use the language of Paley, but "that He might let in, and thereby exhibit, demonstrations of his wisdom." Throughout nature, the exigences and incongruities necessarily arising from the arrangements we have been considering, have given occasion for the display of the most astonishing wisdom and power. And instead of that jarring and clashing, which might have been expected from so many conflicting elements, the qualities and quantities of these elements have, upon the whole, been so wonderfully adjusted to each other, that they neutralize and balance each other's evils; and the general result has been, that all have finally settled down together, into that harmonious state of equilibrium, before alluded to, so admirably adapted for the existence of organic life.

Fifthly. The next point claiming our attention is the nature and relations of the properties with which material molecules have been endowed.

Molecular properties and their relations in general are, in the highest degree, calculated to impress us with exalted notions of the wisdom and power of the Creator. What, for instance, can be more truly admirable than the forces of heterogeneity? those forces by which the molecules of different bodies are associated and separated into new forms, and thus lead to all the mighty changes, and all the astonishing variety we see around us? What more wonderful, than that the same forces when gently and unostentatiously directed, should on the one hand produce objects and changes agreeable and beneficial, nay even necessary to our existence; and on the other hand when differently directed, should give rise to the most terrible displays of energy made known to us—the utmost intensities of heat, of cold, and of light; the terrors of the thunderbolt; the irresistible destruction of the earthquake?

Nor are the forces of homogeneity much less wonderful or less important in the economy of nature. For if the molecules of similar bodies had not possessed forces, both self-attractive and self-repulsive, there would have been no homogeneous aggregation into symmetrical groups; no order or regularity; no separation or purity: in short, there would have been no common bond of union; and the different molecules of every variety of matter would have been dispersed throughout nature, as accident or other circumstances might determine. The present order of things, therefore, could not have existed, unless the molecules of matter had been endowed with both kinds of forces—with the forces of heterogeneity or chemistry, which going before, imperiously determine what molecules shall be combined or separated: and with the forces of homogeneity, which, silent and unobtrusive, follow in the train of heterogeneous forces, and industriously assorting and arranging their predecessors' labours, here, perhaps, form a diamond; or there superintend the integrity of the atmosphere!

Sixthly. We have hitherto confined our attention to general principles, and arrangements; but the commonest chemical process may be made to furnish us with some striking proof of the omnipotence of the Creator. Let us, for example, consider what happens in a simple and familiar instance of chemical decomposition; as when a solution of lunar caustic

(nitrate of silver), is added to a solution of common salt. In this case, the chlorine of the salt combines with the silver, and produces a curdy precipitate, which falls down; while the nitric acid combines with the soda, and forms a soluble salt, which remains in solution. Now, we showed in a former chapter, that the minutest fragment of matter appreciable by our senses, consists of innumerable molecules. If therefore we suppose a small quantity, as an ounce, of the lunar caustic, and a proportionate quantity of common salt, to be mixed together; what countless myriads of molecules, in a portion of time literally inappreciable, must have sought out, and combined, each with its fellow, in this simple process! The human mind absolutely recoils from the contemplation of objects so completely beyond its powers; for the utmost we can imagine, must fall almost infinitely short of the reality. Were we, for illustration, to conceive all the human beings at present in existence, to be collected together into one vast array, and to be all dressed exactly alike, and to perform the same military manœuvre at the same moment; we should be probably as far short of the actual numbers of similar molecules, each manœuvring exactly alike, in the above simple experiment, as a single company falls short of our congregated army!

The above example is meant to illustrate the principles of the argument only: the argument itself, like all the preceding, is strictly cumulative; and applies, more or less, to every operation in nature.

Such is a summary view of the wonders developed by chemistry; and what an idea do they convey to us of the wisdom, and of the power of Him, who contrived and made the whole! Of the capacity of that eternal Mind, who, while He directs the universe; at the same time, takes cognizance, and regulates the movements, of every individual atom in it! To whom, the inmost nature, and end, and object, of every part are familiar; of whose comprehensive designs, the whole forms but a single link; the antecedent and the consequent to which, are alike merged in infinity!

BOOK II.

OF METEOROLOGY.

CH. I.—INTRODUCTORY REMARKS.

IN the First Book we have endeavoured to convey some notion of the "limits which the Deity has been pleased to prescribe to His own power;" or in other words, to describe briefly the properties of the different subordinate agents and elements of our globe; and their laws of operation. We come now, to consider, a little more closely, the general distribution of these agents and elements; and the principles on which this distribution is regulated; so as to produce all the wonderful results, we see constantly going on around us in nature.

In the present state of the world, as we have already observed, the general tendency of its constituent elements, seems to be towards a state of equilibrium, or repose. But a very superficial examination of those parts of the earth's crust, to which we can obtain access, is sufficient to convince us, that this quietude has not always existed; and consequently, that the present state of things must have had a beginning. In short, the phenomena of geology appear to show, that our earth during its progress, has undergone, alternately, periods of comparative quietude, like the state in which we now live; and periods of de-

rangement and convulsion, in which the preceding states of quietude, and their consequences, have been more or less subverted; and a new order of things has been induced. To enter further into details regarding these changes, however, would be quite foreign to the object of the present volume. It is the business of the Geologist, to point out the changes which our earth has evidently undergone, before it arrived at its present condition; to trace the earth, as it were, from a state of chaos, through all its metamorphoses, whether sudden and convulsive, or slow and gradual; and to show, that all these changes have not resulted from chance, but from the agency of an intelligent Being, operating with some ulterior purpose; and according to certain laws, to which He had chosen to restrict himself:—to demonstrate, in fact, that to these very convulsions and changes, we owe all that boundless variety of sea and of land, of mountain and plain, of hill and valley; all that endless admixture of rocks, of strata, and of soils, so essential to the existence of the present order of things; without which the world would have been a mass of crystals, or one dreary monotonous void, altogether unfit for the support of the present races of organized beings, and precluding the existence of man—apparently, one great end and object of creation.

Such is the business of the Geologist; and where his duties terminate, those of the Meteorologist may be said to begin. To the Meteorologist, more especially, it belongs to consider the globe in its present condition of equilibrium; and the means by which this state of equilibrium is maintained: in particular, to point out the influences of heat and of light, and of the energies allied to them; to study the laws of the distribution, and change, of these wonderful agents, in the production of climate; to trace, in short, the effects of heat and light on the earth, the ocean, and the atmosphere; and all the infinite variety of phenomena dependent on them.

In so wide and varied a field of inquiry, it is not easy to devise a plan, that shall be perfectly unexceptionable. For, as there is no one subject so entirely isolated, as not to be more or less influenced by the rest; we scarcely know with which to commence. After a good deal of reflection,

we have adopted that arrangement, which seems to offer the most natural view of these subjects; and at the same time appears best calculated to illustrate the design, and wisdom, of the Great Creator.

CH. II.—OF THE GENERAL STRUCTURE OF THE EARTH: PARTICULARLY WITH REFERENCE TO THE DISTRIBUTION OF ITS SURFACE INTO LAND AND WATER; AND WITH RESPECT TO ITS ATMOSPHERE.

§ 1.—*Of the General Relations of the Sea and the Land to each other.*

OUR earth may be considered to be composed of various solid, liquid, and gaseous materials; the absolute proportions of which to each other, we cannot even conjecture. Of the mean density of the whole, however, we can form some estimate; and philosophers have shown that this density is between five and six, the density of water being supposed to be one.* We can also form a tolerably precise notion of the relative proportions of the surface, occupied by the solid and the liquid materials; and of the pressure and height of the atmosphere, by which these solid and liquid materials are surrounded.

We take for granted, that all are more or less acquainted with the general geographical distribution of land and ocean. We shall, therefore, confine ourselves chiefly to their relative proportions; which are such, that nearly three-fourths of the earth's surface may be said to be covered with water; while, of course, barely one-fourth is occupied by dry land. Of this dry land, it is well-known, by far the greater part is confined to the northern hemisphere; while in the southern hemisphere, the Pacific Ocean exhibits a nearly continuous surface of water,

* The late Mr. F. Bailey gives 5·6747 as the mean density of the earth from all his experiments. See his Essay, entitled "Experiments with the torsion rod for determining the mean density of the Earth."—Vol. xiv. of the Memoirs of the Royal Astronomical Society.

greater than that of the whole dry land of the globe put together. According to the estimate of Humboldt, the dry land in the two hemispheres, is in the ratio of three to one; between the tropics, in the two hemispheres, as five to four; and without the tropics, as thirteen to one; the preponderance being in the northern hemisphere.

The height of the dry land above the general level of the ocean is very various; but its utmost height, as compared with the diameter of the earth, is quite trifling; and, it has been shown, that if the whole of the dry land existing, were equally distributed over the bottom of the sea, the quantity of water in the sea is amply sufficient to cover it entirely. Hence, "dry land can only be considered as so much of the rough surface of our globe, as may happen for the time, to be above the level of the waters; beneath which, it may again disappear; as it has done at different previous periods."*

The solid portions of our earth, are all made up of various combinations of the primary elements, described in a former chapter. The relative situations these elements occupy in the earth's structure; the endlessly varied proportions in which they exist; and all the infinite diversity of their properties, it is the business of the geologist and of the mineralogist to inquire into, and explain; the observations, therefore, which we have to make on the present part of our subject, will be chiefly confined to the waters of the ocean; and to the atmosphere.

§ 2.—*Of the Ocean.*

The waters of the ocean are not pure, but contain, as is well known, a variety of saline matters in solution. Indeed when we reflect on the immense relative extent, and general circumstances of the ocean, we may naturally suppose, that its waters will contain more or less of every existing soluble principle. By far the most abundant principle, however, in sea-water, is common salt; which may be said to constitute, in general, nearly two-thirds of the whole saline matter present. The whole saline matter is between three and four

* De la Beche's Geological Manual, p. 2.

per cent.; and the specific gravity of the water varies, according to the proportion of the saline ingredients, from about 1026 to 1030; pure water being supposed to be 1000. The late Dr. Marcet, some years ago, made a series of interesting experiments on this subject; and the following are the general conclusions which he drew from them:—

1. That the southern ocean contains more salt than the northern ocean, in the ratio of 1·02919 to 1·02757.

2. That the mean specific gravity of sea-water, near the equator, is 1·02777; or intermediate between that of the northern, and that of the southern hemispheres.

3. That there is no notable difference in sea-water under different meridians.

4. That there is no satisfactory evidence that the sea, at great depths, is more salt than at the surface.

5. That the sea, in general, contains more salt where it is deepest, and most remote from land; and that its saltness is always diminished, in the vicinity of large masses of ice.

6. That small inland seas, though communicating with the ocean, are much less salt than the ocean.

7. That the Mediterranean contains rather larger proportions of salt, than the ocean.*

The saltness of the sea is considerably influenced, at least at its surface, by the neighbourhood of large rivers, and by permanent accumulations of ice; and in this way, the inferior saltness of small inland seas, particularly in high latitudes, may in general be explained; as most of these inland seas are supplied with comparatively large quantities of fresh water, from the rivers flowing into them. On the other hand, the superior saltness of the Mediterranean, has been ascribed to the immense evaporation from its surface; the consequence principally, of its being situated in a warm climate.

The saline contents of the ocean are of immense importance in the economy of nature. Such indeed is their importance, that it is doubtful whether the present order of things could be maintained without them. The effects of these saline matters, will be more particularly pointed out afterwards. In this place, we shall only remark, that by

* Philos. Trans. 1819.

lowering the freezing point of water; and by diminishing its tendency to give off vapour; they perform the most beneficial offices. Another valuable purpose they serve, may be alluded to here; viz. the greater power of buoyancy they communicate to water; by means of which, the waters of the ocean are better fitted for the purposes of navigation. Nor are these the only uses of saline matters; for there is reason to believe, that they contribute in no small degree to the stability of sea-water, and that an ocean of fresh water would speedily undergo changes, which would probably render it incompatible with animal life: the waters of such an ocean might even be decomposed, so as seriously to interfere with the other arrangements of nature.

Lastly, who will venture to assert that the distribution of sea and of land, now established, though apparently so disproportionate, is not actually necessary, as the world is at present constituted? What would be the result, for instance, if the Pacific or the Atlantic oceans were to be converted into continents? Would not the climates of the existing continents, as formerly observed, be completely changed by such an addition to the land; and the whole of their fertile regions be reduced to arid deserts? Now, this distribution of sea and of land, so wonderfully adapted as it appears to be to the present state of things, depends of course, in a great measure, upon the absolute quantity of water in the world. While on the other hand, the relative gravity of water, as compared with the gravity of the earth, keeps the ocean within its destined limits, notwithstanding its incessant motion. Thus Laplace has shown, that the world would have been constantly liable to have been deluged from the slightest causes, had the mean density of the ocean exceeded that of the earth! Hence the adjustment of the quantity of water, and of its density, as compared with that of the earth, afford some of the most marked and beautiful instances of design.

§ 3.—*Of the Atmosphere.*

The immense body of gaseous matters surrounding our earth, and usually known under the name of the Atmosphere, is essentially composed, as we formerly stated, of

two primary elements, oxygen and azote, in the proportion nearly of one part of oxygen, and four parts of azote. Besides these two gases, the atmosphere also contains a small, and perhaps a variable, quantity of carbonic acid gas, amounting on an average, to somewhat less than one part in a thousand of the whole; and of water in a state of vapour, likewise a variable quantity, (as will be shown hereafter,) but usually fluctuating between one, and one and a half per cent.* In addition to these ingredients, there are, probably, ammonia and other matters constantly present in the atmosphere; for as the sea contains a little of everything that is soluble in water; so the atmosphere may be conceived to contain a little of everything that is capable of assuming the gaseous form.

The atmosphere exerts a pressure, or weight, upon all parts of the earth's surface, on an average, equal to about fifteen pounds upon a square inch; or in other words, equal in weight to a column of mercury, one inch square, and thirty inches high. The well-known instrument, the common Barometer, or Weather-glass, consists of nothing more than such a column of mercury, poised or pressed upwards into a vacuum by the weight of the atmosphere. With the changes constantly taking place in the height of such a column, every body is familiar; and we shall have occasion again to recur to them: at present, it is only requisite to observe, that these changes are much less remarkable in tropical than in temperate climates. Thus, between the tropics, the barometer usually varies only about one-third of an inch; while in temperate climates, the changes amount to upwards of one-tenth of the whole height.

The pressure of the atmosphere decreases as we ascend above the earth's surface; and for equal ascents, this decrease of density, is, in what is called geometrical pro-

* Or more accurately speaking, 1000 parts of atmospheric air, under ordinary circumstances, may be said to consist of

Oxygen	210·0
Azote	775·0
Aqueous vapour . . .	14·2
Carbonic acid . . .	0·8
	1000·0

gression. Thus, after an ascent of three miles, the density of the atmosphere is found to be only one half of what it is at the surface of the earth, or equal to a column of mercury fifteen inches in height; at six miles the barometer would stand at one-fourth of its usual height, or seven and a half inches; at nine miles of elevation, at three inches and three quarters: and, at fifteen miles, at about one inch only. Hence, though from various circumstances, the atmosphere has been inferred to extend from forty to forty-five miles above the earth's surface; by far the greater portion of it is always within fifteen or twenty miles. The distance, however, to which the atmosphere extends, must be different in different latitudes; for the rotation of the earth on its axis; and the greater, and more direct influence of the solar heat near the equator, will necessarily cause the atmosphere to be higher in the equatorial, than in the polar regions; while at the poles, the atmosphere must be lower than over any other part of the earth's surface.

Much difference of opinion has existed among philosophers, as to the mode in which the primary elements entering into the composition of atmospheric air, are associated; some maintaining that these elements exist simply in a state of mixture: others considering them as chemically united. We formerly stated that all gaseous bodies, when they combine with one another, combine with reference to their volumes; that is to say, that one volume of one gas always combines with one, two, or more similar volumes of the same, or of another gas, and not with any intermediate fractional part. Now, since atmospheric air is essentially composed of one volume of oxygen, and four volumes of azote, it is evident, whether its elements be in actual union or not, that it is at least constituted on strictly chemical principles; whence it follows, that the composition of the atmosphere has not been the result of accident. In this point of view, therefore, atmospheric air may be considered to be as much a chemical compound as water, or any other similar body; and instead of viewing the atmosphere, according to a prevalent notion, as a mere accidental and heterogeneous appendage, connected with the denser matters by no appa-

rent tie; we may fairly rank the atmosphere among the constituents of our globe; and as forming a symmetrical part of the great harmonious whole.

But although atmospheric air has been thus originally constituted on chemical principles, and probably owes its stability, in no small degree, to this circumstance; yet the mode in which its constituent elements are associated, is very different from the mode in which the elements of compounds in general, are associated. Indeed the constituted elements of atmospheric air, do not appear to be combined at all; but to be only mixed, or simply diffused through each other, in the same manner as the minute portions of carbonic acid gas, and of vapour, are known to be diffused through the whole atmosphere; that is to say, according to the laws of general diffusion of gaseous bodies, which we endeavoured to explain in a former chapter. To this explanation we must refer the readers for details. We shall merely observe here, that the fundamental principle of this explanation consists in the assumption, that the molecules of all bodies in the gaseous state, are self-repulsive (or repulsive of one another, in preference to others). When different gaseous bodies, therefore, are mixed together, they will not assume a position according to their specific gravities, as they might otherwise be expected to do; but the molecules of each gas will be equally diffused throughout the whole space occupied by the mixture. Hence, one direct and most important effect of the mixed constitution of the atmosphere, is its nearly uniform composition, at least within the limits attainable by man:—a fact which has been confirmed by innumerable analyses of the air, made in all parts of the world; both at its surface, and at the greatest heights man has hitherto reached. Moreover, this constitution of the atmosphere, not only originally produced such uniformity of composition; but is the cause constantly operating to preserve that uniformity—the grand conservative principle, as it were, preventing any unequal distribution of the constituent elements of the atmosphere; which would speedily prove fatal to organic life! Were the gaseous elements composing the atmosphere in ever so slight a state of union, they could not readily diffuse themselves

through each other; and partial accumulations of one or other of them would be constantly taking place; but as the atmosphere is at present constituted, if a little more oxygen be consumed in one spot than in another; instantly the deficiency is supplied from the neighbourhood by diffusion; and the equilibrium is scarcely affected in any sensible degree.

Another curious result of this independent condition of the gaseous elements of the atmosphere is, that of the whole pressure exerted, each component of the atmosphere exerts its own force, according to its quantity. Thus, of the thirty inches of mercury supported by the whole atmospheric pressure, the azote sustains $23\frac{36}{100}$ inches, and the oxygen $6\frac{18}{100}$ inches; while the aqueous vapour sustains only $\frac{44}{100}$ inch, and the carbonic acid still less, or only $\frac{2}{100}$ inch. Hence it is evident, that the fluctuations in the height of the barometer (amounting to nearly three inches in our latitude) cannot depend altogether on the quantity of aqueous vapour in the atmosphere; for if the whole of this vapour were annihilated, it would scarcely produce a difference in height of half an inch. Attention is now drawn to this fact, for purposes which will appear in a subsequent chapter.

Lastly, had the absolute quantity, or the relative gravity, of the atmosphere, been materially different from what they are, the present order of things could not have existed. So that the same striking evidences of wise adjustment are displayed, in these arrangements of the atmosphere, as in the arrangements formerly shown to prevail, with respect to the quantity and the gravity of the waters of the ocean.

Before we close the present chapter, let us reflect for a moment, on the great arrangements we have been considering.

Why has the surface of this earth been divided into land and sea? Why have the land and the sea been so adjusted to each other, that their condition and proportions hardly admit of change, without destruction to the whole fabric? Why has their present stability been so wonderfully secured? Again, with respect to the atmosphere; why has any atmosphere been thrown around this

globe? and why such evident provisions to maintain its ubiquity, and unvarying constitution?

Viewed alone, and without reference to organized beings, all these things appear to want an object. This globe might have revolved about the central luminary—might have occupied its point in the universe, without any "gathering together of the waters,"—without any circumambient air. But the scheme of the great Creator extended beyond the mere adaptation of inanimate matter. "Before its foundations were laid," He had destined this earth to teem with life; and throughout, has rendered it a fit habitation for living beings. For this purpose, and acting, at the same time, in strict conformity to those laws, by which He had chosen to limit Himself, He has, by means of successive convulsions and changes, so contrived to mix and blend the different elements, and finally, so to arrange the dry land apart from the sea, that, taken as a whole, and with reference to the present order of things, their relative proportions will scarcely admit of materia change. While, to crown his works, and as it were, the more strongly to evince his design and his wisdom, He has surrounded this globe with an atmosphere; and to preserve the homogeneity of this atmosphere, its principles have been so associated, as to constitute an exception to His usual operations, and even to the general laws of nature!

CH. III.—OF HEAT AND LIGHT AND THE MODES OF THEIR COMMUNICATION.—OF THE GENERAL TEMPERATURE OF THE CELESTIAL REGIONS AND OF THE EARTH, INDEPENDENTLY OF THE SUN.

§ 1.—*Of the Communication of Heat and Light.*

THE modes by which heat and light are communicated from one body to another, and through the same body, have been already explained, and we need not again enter into details: yet a brief recital here, of the actual modes of communication of heat and light among the objects of nature, may not be unacceptable to the general reader.

Heat passes from the sun to the earth by radiation; and again, by the same process, it is freely sent off from the surface of the earth into the atmosphere. Below the surface of the earth, heat penetrates in all directions through the solid matter, by what is called conduction. A third mode in which this powerful agency is extended over our globe, is by the means we have termed convection, or the carrying process. Convection is confined, of course, to fluids, as water and air. A portion of water or of air being heated above, or cooled below the surrounding portions, expands or contracts in magnitude, and thus becoming specifically lighter or heavier, rises or sinks accordingly, carrying with it the newly acquired temperature, whatever that temperature may be.

Light, as far as it is at present known, moves from one body to another only by radiation.

Bearing in mind these modes of the communication of heat and light, the general reader will find no difficulty in understanding what follows.

Of the Temperature of the Celestial Regions.—From the close and intimate relations between heat and light, and from their almost invariable association as they exist around us, it seems not very unreasonable to conclude, as we did formerly, that these agencies are generally associated in nature, and that wherever one is present, there the other must be present also. If this be really the case, the innumerable fixed stars, considered to be so many suns, must be supposed capable of diffusing heat, as well as light, throughout the celestial regions; and consequently there must be a certain degree of temperature common to the whole. For this reason, and for others which might be mentioned, philosophers have not only inferred the existence of such a common temperature throughout the celestial regions, independently of our sun, but have even attempted to determine its degree. Moreover, all the different modes which have been employed to estimate this temperature, singularly coincide in showing, that it does not differ much from —58° of Fahrenheit's scale.* The temperature of

* It may be proper to observe, that this point has been much unsettled by more recent inquirers, who have in different instances estimated the temperature of space between 9° and — 280° of Fahrenheit's scale!

space is, therefore, supposed to be about 90° below the freezing point of water; a degree of cold "not greatly inferior to that at which quicksilver becomes solid, and much superior to some degrees of cold which have been produced artificially."* If such a common temperature do indeed extend throughout space, or at least through our planetary system, it must have no inconsiderable influence upon the temperature of the planets generally; and with respect to our own globe in particular, such a common temperature must operate, by diminishing the intensity of the cold around the poles.

Of the Temperature of the Interior of the Earth.—The attention of philosophers has, for some years past, been a good deal directed to the internal temperature of the earth, at great depths, beyond the influence of the sun, or of any other external cause. From the earliest times, some vague notions of a central heat seem to have prevailed among mankind: doubtless, arising from their attention being forcibly drawn to the phenomena of volcanoes, and hot springs, but it is not till a comparatively late period that the subject has been carefully investigated. It would be quite foreign to our present purpose to enter here into details; we shall therefore merely state, that the arguments in favour of the probability of a central heat, are—"first, the experiments made in mines, which, notwithstanding their liability to error from various sources, still seem to show, particularly those made in the rock itself, an increase of temperature from the surface downwards;—secondly, the existence of thermal springs, which are not only abundant among active and extinct volcanoes, but also among all varieties of rocks in various parts of the world;—thirdly, the existence of volcanoes themselves, which are distributed over the globe, and present such a general resemblance to each other, that they may be considered as produced by a

For recent information on this interesting subject the reader is referred to an admirable report on meteorology by Professor Forbes, of Edinburgh; Trans. of the British Association for the advancement of Science, 1840.

* Discourse on the Study of Natural Philosophy, p. 157. By Sir J. F. W. Herschel.

common cause, and that cause, probably, deep-seated;—and lastly, the terrestrial temperature at comparatively small depths, which does not coincide with the mean temperature of the air above it."*

Such is an abstract of the principal arguments which have been brought forward in support of the opinion, that within our earth, even at the present time, there exists a central heat of great intensity. As corroborative of the same views, may be mentioned the evidence derived from the characters of the fossil remains both of plants and of animals, found in the colder regions of the world; which characters are such, as to prove beyond a doubt, that these plants and animals must have been produced in a climate much hotter than that in which their remains are found; and indeed, that the heat of the climate in which they lived must have been equal, if not superior, to the heat of the tropical portions of our earth at the present time. Hence it has been inferred, that the temperature of our earth, formerly much above what it is now, has been gradually dissipated into the surrounding planetary regions, and has thus helped to increase the general temperature, which, as above stated, is supposed to pervade space. Moreover, the Baron Fourier, to whom we are principally indebted for these observations, has attempted to show, that the earth has nearly reached its limit of cooling, particularly near the surface. Near the surface, the temperature would necessarily decrease much more rapidly than in the interior; where, in a globe of the earth's magnitude, the temperature might be supposed to remain nearly unchanged, for a very great length of time. The same distinguished philosopher has also attempted to show, that the temperature of the surface is still liable to be influenced by the gradual escape of heat from the interior, which even yet seems to be constantly going on; and that the temperature of the surface is thus somewhat higher, than it would be, if such central heat did not exist; or than it would be, if the temperature of the surface of the earth depended only on the action of the sun.

* De la Beche's Geological Manual, p. 24, new edit. The temperature of the interior of the earth has been found to increase 1° of Fahrenheit's scale, at distances varying from every 37 to every 76 feet.

We are thus brought to the proper commencement of this treatise on Meteorology; viz. the consideration of the present state of the earth's temperature, as liable to be influenced by the presence or absence of the sun, the great source of heat and of light to our system.

Before proceeding, we may remark, that the details of the subject we have now concluded, fall entirely within the province of the geologist. To him it belongs, as we have already said, not only to trace the wonderful changes which our globe has undergone in arriving at its present condition; but to point out, the beautiful adaptations of organic life, and structure, to the existing circumstances of its various epochs. Considered in this point of view, geology is a subject of the highest interest and importance; and, to use the words of an eminent Professor, with which we shall finish this chapter, "lends a great and unexpected aid to the doctrine of final causes; for it has not merely added to the cumulative argument, by the supply of new and striking instances of the mechanical structure adjusted to a purpose, and that purpose accomplished; but it has also proved, that the same pervading active principle manifesting its power in our times, has also manifested its power in times long anterior to the records of our existence.

"But, after all," continues our author, "some men, seeing nothing but uniformity and continuity in the works of nature, have still contended (with, what I think, a mistaken zeal for the honour of sacred truth) that the argument from final causes proves nothing more than a quiescent intelligence. I feel not the force of this objection. In geology, however, we can meet it by another direct argument; for we not only find in our formations organs mechanically constructed, but at different epochs in the history of the earth, we have great changes of external conditions, and corresponding changes of organic structure; and all this without the shadow of a proof, that one system of things graduates into, or is the necessary and efficient cause of the other. Yet in all these instances of change, the organs, as far as we can comprehend their use, are exactly those which were best suited to the functions of the being. Hence we not only show intelligence contriving means adapted to an end,

but, at successive times and periods, contriving a change of mechanism adapted to a change in external conditions. If this be not the operation of a prospective and active intelligence, where are we to look for it ?" *

Ch. IV.—Of the temperature of the earth at its surface, as dependent on the sun.

The general temperature of the earth is doubtless regulated by its situation in the universe; and more especially by its position with respect to the sun. To this position of the earth, as formerly observed, the properties of its constituent elements have, most obviously, been all adapted with consummate wisdom; so that, under the circumstances in which they are placed, some are solid, some liquid, others gaseous, according to the purposes they are intended to fulfil in nature.

But the heat and light derived from the sun, are very unequally distributed over the surface of the earth; and every one is familiar with the fact, that as we recede from the equator toward the north or south, the temperature of the earth's surface gradually diminishes, till we arrive at the polar regions.

Such is the general fact. But the circumstances which conspire to interfere with this gradual distribution of temperature, are so numerous and so influential; that the actual temperature of a place can be learnt only by observation. Among the circumstances thus more especially affecting the distribution of temperature, may be mentioned, the nature of the surface, whether water or land;—and the situation, whether at a greater, or at a less height, above the level of the ocean. To such circumstances may be added, the particular configuration and geographical relation of places; as their aspect to the north or south; their being sheltered or

* Address delivered to the Geological Society of London, by the late President, Professor Sedgwick, 1831.

exposed; the composition and nature of the soil, particularly its colour and state of aggregation; on which depend its powers of absorbing and of radiating heat and light; and of retaining or of parting with humidity, &c.; also the proximity, or absence of, seas; the predominance of certain winds; the frequency of clouds, fogs, &c. These, and innumerable other circumstances, many of which will be pointed out in subsequent chapters, contribute to influence the temperatures of different places; and to render them, in fact, as varied as the places themselves.

Nor is difference of place, the only cause of difference of temperature; every one knows, that at the same place, the temperature is in a constant state of change. Hence, before we can obtain correct notions of the actual temperature of any given place, or period, certain expedients are necessary, which it will be requisite first to consider.

§ 1.—*Of Mean Temperature.*

If, on any given day, we observe the temperature at the earth's surface, at the commencement of every one of the twenty-four hours, we shall find, as before observed, that at each hour the temperature is different; and we naturally inquire, which of all these temperatures is to be chosen in preference, as the one characteristic of the day and place? The answer to this question obviously is; that temperature, whatever it may be, which is equidistant from the extremes; or, as it is usually termed, the mean temperature of the whole. Now this mean temperature may be obtained, nearly, by adding all the results together, and dividing the sum by the number of observations; thus we arrive at the mean temperature of the day, by adding together the temperatures observed at different hours of the day, and dividing the sum by the number of temperatures. In like manner, by adding together the mean temperatures of every day of a week, or of a month, and dividing the sum by the number of days, we obtain the mean temperature of the week or month; and so on, by similarly treating the mean temperatures of the months, or of any number of years, we obtain the mean temperature of the year, at a given place: and it

is to be remembered, that the more numerous the observations, the more accurate will be the mean result.

Lastly, it remains to state, that the temperature always understood by the Meteorologist, (unless otherwise expressed,) is the temperature of the air near the surface of the earth, as indicated by a thermometer, effectually protected from radiation and foreign influence of every kind. The temperature as indicated by a thermometer fully exposed to solar radiation, and which in its turn is allowed to radiate freely in the sun's absence, is altogether a different thing; and may be imagined to coincide very nearly with the actual temperature of the earth's surface, when similarly exposed. The fluctuations of temperature indicated under these circumstances, are much greater than those of the air above noticed; though it is probable, that the mean of the whole of such observations, if this mean could be accurately obtained, would differ little from the mean of the fluctuations of the temperature of the air.

§ 2.—*Of the Polar and Equatorial Temperatures; Of Isothermal Lines; and Of the actual Distribution of Temperature over the Earth.* CLIMATE.*

The reader is supposed to be acquainted with the principles of the common division of the surface of the globe into five zones or bands, usually denominated the torrid, the two frigid, and the two intermediate, or temperate zones; and that generally speaking, the poles, and the equator, present the extremes of temperature upon the earth's surface. Now, in considering the general distribution of temperature over the globe, the extreme temperatures naturally claim our attention in an especial manner: we shall, therefore, begin with the temperature of tho polar, and of the equatorial regions.

Of the Temperature of the Poles, and of the Polar Regions.—The probable mean temperature of the poles has always been an interesting subject of meteorological inquiry. It must be confessed, however, that after all that of late years has been dono by our enterprising countrymen, much is yet necessary, to enablo us to arrive at

* See the Map.

satisfactory conclusions. Thus it has been shown, that in attempting to calculate the temperature of the North Pole, we shall obtain very different results, by employing the temperature occurring in the old world, and that observed in the new world; the temperature of the old world indicating the temperature of the pole to be about 10°; while the temperature of the new world, indicates it to be considerably below Zero. Hence it has been inferred, that there are two points or poles of greatest cold, situated in about the latitude of 80° north, and in longitudes 95° east, and 100° west; and consequently, that the geographical pole of the globe, is not the coldest point of the Arctic hemisphere. Whether this deduction be well founded or not, must be decided by future observation. At present, the actual temperature of the Polar regions cannot be considered as determined.

Although we are thus unable to state with certainty the temperature of the Polar regions, it may nevertheless be deemed an object of curiosity, to know the lowest temperatures that have been noticed. Perhaps the lowest authentic observations of temperature we possess, are those by Captain Parry at Melville Island. There, the thermometer in the ship, was often observed as low as —50°; and at a distance from the ship, even as low as 55° under Zero. We believe still lower temperatures than these are on record, but probably they are not to be relied on. The greatest degree of cold hitherto produced artificially, has been 91° under Zero.

Of the mean annual Temperature of the Equator.—The mean annual temperature of the equatorial, like that of the polar regions, is a meteorological problem of considerable interest. Humboldt, from a very extensive generalization, fixed the mean equatorial temperature at 81½°; and the same mean has been adopted by others. Attempts, however, have been recently made to show that this temperature is 3° or 4° below the truth; but Humboldt in reply still maintains his former opinion. Since at the equator, only about one-sixth of the whole circumference of the globe is dry land; the general equatorial temperature, as actually found to exist, is perhaps lower than upon theoretical principles it ought to be, as deduced from obser-

vations made on the continent in the neighbourhood of the equator. Thus the mean temperature of Pondicherry, in latitude 11° 55′ north, is at least 85°; and if from this temperature, the temperature of the equator were deduced according to the common principles, the deduction would of course be much above the truth. The fact is, as in the case of the Polar regions, we do not possess the requisite data for determining the equatorial temperature, in a perfectly satisfactory manner.

As in speaking of the Polar regions, we noticed the lowest degree of temperature which had been observed: perhaps while speaking of the equatorial regions, it may be deemed not irrelevant, to notice the highest temperature. Observations, however, of this kind, being principally founded on the incidental notices of travellers, are not, in general, much to be relied on; or are to be considered only as approximations. Thus the thermometer has been recorded at Benares to stand at 110°, 113°, and even 118°. At Sierra Leone, it has been observed, when placed on the ground, to indicate a temperature of 138°. Humboldt also gives many instances of the temperature of the surface of the earth, amounting to 118°, 120°, and 129°: and on one occasion he found the temperature of a loose and coarse granitic sand, to amount to upwards of 140°; the thermometer in the sun at the time, only indicating a temperature of about 97°.

Of the Temperature of the intermediate Regions of the Globe. Of Isothermal Lines, &c.—With respect to the temperatures of those parts of the earth, between the poles and the equator, it may be remarked, that, except for reference only, the old division, before mentioned, of the earth's division into zones, is now almost entirely superseded by the more precise and natural arrangement, termed the Isothermal arrangement. According to this arrangement, all the places upon the globe, having the same annual mean temperature, are classed together; and lines drawn upon a map through such a series of places have been termed Isothermal lines, or lines of equal temperature. As might be expected from what has been already stated, the courses of these lines are by no means regular. Thus, suppose two travellers set out, the one from London and

the other from Paris; and each visits all the places in the northern hemisphere, in which the mean annual temperatures are the same as in these two cities. It will be found that the lines of their routes, or the isothermal lines of these two cities, will not only not follow the parallels of their latitude, but that they will not be parallel to each other; and the same may be said to be the case, with any other two places upon the globe. Hence, as the isothermal lines are as numerous as the places, and as diversified as numerous, geographers have grouped them into bands or zones. Thus Humboldt, to whom we owe most of what has been done on this subject, has divided the northern hemisphere into the following six isothermal bands, or zones, viz.

1.	The zone of	mean	annual temperature	ranging	from 32° to 41°.
2.	,,	,,	,,	,,	from 41° to 50°.
3.	,,	,,	,,	,,	from 50° to 59°.
4.	,,	,,	,,	,,	from 59° to 68°.
5.	,,	,,	,,	,,	from 68° to 77°.
6.	,,	,	,,	,,	from 77° upwards.

The tables given in the appendix contain a general view of Humboldt's results. From these results, and from other data, the approximate courses of the different isothermal lines have been traced on the accompanying map*; which will convey to the reader a much more distinct notion of their nature, than can be conveyed by words. We shall therefore content ourselves with briefly pointing out the approximate course of the most interesting of these lines; viz. the Isothermal line of 32°.

If we begin to trace this important line from the eastern parts of Siberia in longitude 130° east, we shall find that in that meridian it commences nearly in the latitude of 59° north; whence it makes a gradual bend northward, and crosses the parallel of 60°, nearly in longitude 90°. From that point, it still advances to tho north, and crossing the arctic circle in longitude 45° east, arrives at its most northern extremity in about latitude 67½°, longitude 10° east. From this, its most northerly limit, tho line takes a gradual sweep toward the south; recrosses the arctic circle in longitude 15° west, and passing through the north-west of Iceland, divides the parallel of 60°, in longitude

* See Appendix p. 396.

42° west. Thence the line proceeds southward to the latitude of 54°, a little to the north of Table Bay, in Labrador; gradually declining in its course till it arrives at longitude 100° west, in the central parts of the new continent. The Isothermal line of 32°, ranges, therefore, through a space of 14° or 15° of latitude: while its western extremity, in the central parts of America, is 5° or 6° nearer the equator, than its eastern extremity in Siberia—a circumstance strikingly illustrative of the greater cold of the new continent, in the same parallel of latitude. The other Isothermal lines are represented approximately on the map, and do not require to be more minutely described. The most remarkable circumstance connected with them is, that as they approach the equator, they gradually become less convex toward the north; so that the Isothermal line of 77° differs but little from a straight line, coincident with the tropic of Cancer.

In the arrangement above described, the mean temperatures of the whole year are supposed to be classed together; but it is obvious that the same principle may be applied to any portion of the year; as the extreme winter and summer temperatures. Such classifications are often, as we shall presently see, of great importance in enabling us to estimate the characters of a particular country. Lines drawn through places having the same summer, and the same winter temperatures, are denominated Isotheral and Isocheimal lines; while lines drawn through places having other common temperatures, receive other appropriate names.

The similarity and diversity of the seasons arising from the actual distribution of Temperature over the Earth, are graphically pointed out in the extract from Humboldt, regarding the northern hemisphere.

"The whole of Europe," says this distinguished philosopher, "compared with the eastern parts of America and Asia, has an insular climate; and upon the same Isothermal line, the summers become warmer, and the winters colder, as we advance from the meridian of Mont Blanc towards the east or the west. Europe may be considered as the western prolongation of the old continent; and the western parts of all continents are not only warmer, at equal lati-

tudes, than the eastern parts; but even in the zones of equal annual temperature, the winters are more rigorous, and the summers hotter, on the eastern coasts, than on the western coasts, of the two continents. The northern part of China, like the Atlantic region of the United States, exhibits seasons strongly contrasted; while the coasts of New California, and the embouchure of the Columbia, have winters and summers almost equally temperate. The meteorological constitution of countries toward the north-west, resembles that of Europe as far as 50° or 52° of latitude. Comparing, in the two systems of climates, the concave and the convex summits of the same Isothermal lines; we find at New York, the summer of Rome, and the winter of Copenhagen; at Quebec, the summer of Paris, and the winter of St. Petersburgh. At Pekin, also, where the mean temperature of the year is that of the coasts of Brittany, the scorching heats of summer are greater than at Cairo, and the winters are as rigorous as at Upsal. So also, the same summer temperature prevails at Moscow in the centre of Russia, as toward the mouths of the Loire, notwithstanding a difference of 11° of latitude; a fact that strikingly illustrates the effects of the earth's radiation on a vast continent deprived of mountains. This analogy between the eastern coasts of Asia and America sufficiently proves," continues Humboldt, "that the inequalities of the seasons depend on the prolongation and enlargement of continents toward the pole; on the size of seas in relation to their coasts; and on the frequency of the north-west winds; and not on the proximity of some plateau, or elevation, of the adjacent lands. The great table lands of Asia do not stretch beyond 52° of latitude; and in the interior of the new continent, all the immense basin, bounded by the Alleghany range, and the rocky mountains, is not more than from 656 to 920 feet above the level of the ocean."

The general temperatures of the northern and of the southern hemispheres, are understood to differ very considerably. This difference, however, does not depend on any material difference in the proportion of heat and light derived from the sun, as will presently be shown, but on the very unequal distribution of sea and of land in the two

hemispheres; the small quantity of land in the southern hemisphere contributing to equalize the seasons.

Humboldt has shown that near the equator, and indeed so far south as 40° or 50°, the similar Isothermal lines are in both hemispheres almost equally distant from the poles; and that, in considering only the transatlantic climates between 70° and 80° of west longitude, the mean temperatures of the year, under corresponding geographic parallels, are even warmer in the southern than in the northern hemisphere. It is the division of heat, therefore, between the different seasons of the year, rather than the absolute amount of heat during the whole year, which gives a peculiar character to southern climates, and approximates them generally to the character of insular climates. The mean temperature is not precisely known beyond 51° of south latitude; yet there is no reason to believe that the Isothermal line of 32° is much further from the south pole than, in the opposite hemisphere, the similar line is from the north pole: and some circumstances at first sight appear to show, that the Isothermal line of 32° is even nearer to the south pole than it is to the north pole, though these circumstances are probably deceptive. With respect to the temperature of the south pole itself, like that of the north pole, we have no means of forming on accurate estimate.*

Such is a summary account of the general distribution of temperature, over the northern and southern hemispheres. Now, amidst the infinite changes everywhere going on, there is, nevertheless, at the same place a certain average state of things which, taken together, constitute what is called the CLIMATE of the place. Of climate, undoubtedly, temperature is the most important ingredient. But the circumstances, besides mere temperature, which enter into the formation of climate, are so numerous and diversified, and their operation, in consequence, is so complicated, that it becomes exceedingly difficult to unravel and display them in a satisfactory manner. The constituents of climate, however, appear to be most naturally divided into two great sections, viz.—

Constituents of climate of a PRIMARY kind, depending

* Further interesting details respecting the temperature of the southern hemisphere will be found in the narratives of recent voyages.

on the globular figure of the earth; on its motion in its orbit, and on its motion on its axis: and

Constituents of climate of a SECONDARY, or subsidiary kind, more immediately connected with the globe itself, and depending on the nature of its surface, as composed of land or water; or, as connected with its atmosphere.

Under these two divisions, we purpose to consider the subject of CLIMATE, in the following chapters.

CH. V.—OF THE PRIMARY CONSTITUENTS OF CLIMATE: OR, OF THE TEMPERATURE OF THE EARTH, AS DEPENDENT ON ITS GLOBULAR FORM; AND ON ITS ANNUAL AND DIURNAL MOTIONS.

THE distance of the earth from the sun is such that the solar rays may be supposed to arrive at the earth's surface in a state of parallelism. Now, when parallel rays fall upon a globe, it is obvious, that any number of such rays falling perpendicularly, as at the equator of our earth, will occupy a very different portion of the surface of the globe; from what an equal number of the same rays will occupy, where they fall obliquely, as in our polar regions. Hence, as we recede from the equator toward each pole, heat and light are diffused over gradually increasing portions of the earth's surface, and thus the intensity of both decreases in a like proportion. The exact law of such decrease is well known to mathematicians, but need not be here stated. For our present purpose it is sufficient to observe, that among the natural causes affecting the distribution of heat and light in different latitudes, the globular figure of the earth is the principal.

The second great natural cause of the unequal distribution of heat and light over the earth, is the obliquity of the earth's motion in its orbit, with respect to the plane of its equator. From this obliquity it happens, that, during the annual revolution of the earth round the sun, every part of its surface, between the latitudes of 23½° north and south from the equator, is in turn exposed to the perpendicular influence of the sun. To this obliquo motion of

the earth in its orbit, we owe the endless variations and vicissitudes of seasons in different latitudes.

There is also another circumstance connected with the earth's motion in its orbit, which, as partaking of the character of a primary cause, may here be briefly noticed. The earth's orbit is not a circle, but an ellipse, of which the sun occupies one of the foci. Now, it has been so arranged that in the middle of our winter, the earth is in that part of its orbit which is nearest to the sun. The earth, therefore, is at Christmas actually about three millions of miles nearer to the sun, than at Midsummer. Hence it might be inferred, that the temperature of the southern hemisphere, which during our winter is directly exposed to the sun, would be affected by this greater proximity. Such, however, is not the case; for this greater proximity to the sun, is almost exactly counterbalanced by the swifter motion of the earth along this part of its orbit. The eccentricity of the earth's orbit, therefore, has little or no influence on its temperature, as at first sight might be supposed.*

The third great natural cause affecting the distribution of heat and light over the earth, is the earth's revolution on its axis. To this revolving motion we owe the innumerable minor vicissitudes of temperature, and of light and shade, daily and hourly experienced throughout the world.

Such are the three great natural causes which regulate the distribution of heat and light over our globe. They may be considered as the necessary results of more general laws, to which the Great Author of nature has chosen to

* Or, to quote the more precise explanation of Sir J. Herschel, "The momentary supply of heat received by the earth from the sun, varies in the exact proportion of the angular velocity, that is of the momentary increase of longitude. Hence the greater proximity of the sun in the winter, is exactly compensated for, by the earth's more rapid motion; and thus an equilibrium of heat, is, as it were, maintained. Were it not for this, the eccentricity of the orbit would be, to exaggerate the difference of summer and winter in the southern hemisphere, and to moderate it in the northern; thus producing a more violent alternation of climate in the one hemisphere, and an approach to perpetual spring in the other. As it is, however, no such inequality subsists; but an equal and impartial distribution of heat and light is accorded to both." Treatise on Astronomy, p. 198, (Cabinet Cyclopædia).

restrict himself, and to which, as usual, He most rigidly adheres. Why, among the numerous possible means by which heat and light might have been, and in other instances are, distributed from a central sun over a distant planet, these regulating causes have been selected for our earth, is absolutely unknown to us. We cannot hesitate to believe that this selection has been made with some ulterior view; and one such view or purpose may have been to demonstrate to us His wisdom and His power by the methods chosen, for obviating the difficulties necessarily resulting from these primary arrangements. In other planets, where other primary arrangements for the distribution of heat and light have been adopted; there are probably other modes of obviating the difficulties arising from them. Of such arrangements we can form no conception; but to the inhabitants of these planets, they are doubtless an equal evidence of the wisdom and the power of the Deity.

CH. VI.—OF THE SECONDARY, OR SUBSIDIARY CONSTITUENTS OF CLIMATE: COMPREHENDING A SKETCH OF THOSE CIRCUMSTANCES CAPABLE OF INFLUENCING CLIMATE, WHICH ARE MORE IMMEDIATELY CONNECTED WITH THE SURFACE OF THE EARTH, AS CONSISTING OF LAND OR WATER; OR WHICH ARE CONNECTED WITH THE ATMOSPHERE.

IN the preceding chapter we have alluded to the difficulties, or exigencies necessarily arising from the modes in which heat and light are distributed over our earth; and of these modes of distribution, before we proceed, it may be proper to specify some of the most striking.

Had the heat and light derived from the sun to the earth, not been in any way modified; the equatorial and the polar regions would have been alike inaccessible to organic life. The heat within the tropics, and the cold toward the poles, would both have been destructive; while the intermediate regions would have been exposed to a constant succession of violent and sudden alternations of temperature, which would have rendered the present state of things no less an impos-

sibility. In order, therefore, to render this earth an appropriate dwelling-place for such beings as at present occupy its surface, it was necessary that these extremes, and sudden vicissitudes of temperature should be in some way diminished or alleviated. Accordingly, the regulation of the temperature of our globe has been effected with the most consummate wisdom. Indeed, some of the most splendid instances of design in nature, are offered by those subsidiary arrangements, by which the difficulties, necessarily arising from the primary arrangements, are obviated and mitigated; and by which the greater portion of the earth's surface, has been made accessible to organic beings of the same general character. These subsidiary arrangements it will be our business to explain in the present chapter.

The secondary or subsidiary constituents of climate naturally divide themselves into two great sections; viz., Constituents of climate connected with the surface of the earth, as composed of land and water; and constituents of climate connected with the atmosphere.

In the following outline of these two great divisions of the secondary constituents of climate, we have endeavoured, as usual, to elucidate principles, rather than to enter into details; and, as far as is compatible with a general and popular view, have attempted to point out the modes, in which the laws of light and heat, described in the first Book, operate; so as to produce the phenomena of climate.

§ 1.—*Of the secondary Constituents of Climate, immediately connected with the Surface of the Earth; and depending on the Nature of that Surface as composed of Land or Water.*

In attempting to illustrate the operation of the laws of heat and light in the formation of climate, we shall invert the order, in which these laws were discussed in the previous chapters; that is to say, we shall first consider the influence of heat and light, as depending on their latent and decomposed forms; and afterwards, their influence as depending on their radiation, conduction, and convection.

In the prosecution of this difficult inquiry, the first circumstance which naturally claims our attention, is the

absolute quantity of heat and light, derived from the sun to the earth.

1. *Of the Proportion of Solar Heat and Light, which actually arrives at the Surface of the Earth.*—Of the absolute quantity of heat and light derived from the sun to our globe, we have no means of forming an exact estimate. M. Pouillet has attempted to show, that the amount of heat annually received by the earth from the sun, is equal to the heat which would be required to melt a stratum of ice nearly forty-six feet thick, and covering the whole surface of the earth. This estimate, however, is to be viewed only as a rude approximation.* The difficulty consists, not only in the impracticability of forming precise notions of the heat and light, which actually arrive at any given place in a given time; but in the utter impossibility of forming even a conjecture, of those portions, which become latent, or are otherwise lost, in the passage of the solar rays through the atmosphere. The following observations will give some idea of the absolute quantity of light and heat which reach the earth; but it is proper to apprize the reader, that the results stated, are to be considered as liable to much uncertainty.

A vertical ray of light, in its passage through the clearest air, has been calculated to lose at least a fifth part of its intensity, before it reaches the earth's surface. From this cause, and from the actual condition of the atmosphere, it has been estimated, that under the most favourable circumstances; of a thousand rays emanating from the sun, only 378 on a medium, can penetrate to the surface of the earth at the equator; 228 at the latitude of 45°; and 110 at the poles; while in cloudy weather, these several proportions are a great deal less.†

The absorption of incident solar heat traversing the atmosphere vertically in clear weather, has been estimated from the mean of several observations, to be about 27·7 per cent.‡

* Elémens de Physique expérimentale et de Météorologie, tom. ii. p. 704. M. Pouillet has more recently estimated the amount of heat annually derived from the sun as capable of melting a stratum of ice upwards of a hundred feet in thickness! A sufficient proof of the uncertainty of such estimates.

† Article CLIMATE in the Encyclopædia Britannica.

‡ See Professor Forbes' Meteorological Report, p. 64

At present, our attention is solely directed to the portions of heat and light which thus make their way to the earth's surface. On those portions retained in the atmosphere, we shall offer a few remarks hereafter.

2. *Of the Distribution of Heat and Light over the Earth's Surface in the latent Form.*—The distribution of heat and light in the latent state over the surface of the globe, probably follows laws, nearly similar to the laws which regulate the distribution of sensible heat and light, formerly mentioned; that is to say, the quantity latent, like the quantity sensible, diminishes from the equator toward the poles. We want, however, the necessary data, even for forming an opinion, much more for determining the amount and the exact law of distribution; a subject which must be left for future inquirers. But of the infinite importance of the latency of heat, in the economy of nature, the following brief remarks will serve to convey some notion.

Let us take the familiar instance of water; the fluid which displays the influence of the latency of heat perhaps in a more striking manner than any other substance in nature. We formerly showed, that the temperature of water in becoming solid on the one hand, and gaseous on the other, makes, as it were, a pause, and that its changes never take place abruptly. The consequence of this arrangement is, that ice and vapour are formed slowly and gradually, and as slowly and gradually again become water, while sudden transitions from one state to the other are thus entirely prevented. Were it not for this beautiful provision, we should be constantly liable to inundations, and other inconveniences, which would have rendered the world absolutely uninhabitable. It is impossible, therefore, to reflect on the arrangement itself, or on the means by which it has been effected, without being impressed with the most profound admiration, not only of the wisdom of the Great Designer of the whole, but of His goodness and benevolence.

3. *Of the General Distribution of Electricity and Magnetism over the Earth.*—The discovery of the connexion of electricity and magnetism, formerly detailed, has thrown much light on the distribution of these important agencies over the globe: the present extent of our knowledge re-

garding them, will be comprehended by the general reader from the following summary.

Every one is acquainted with the ordinary phenomena of a magnetic needle freely suspended, and with its tendency to assume a position more or less approaching parallelism to the earth's axis; that is to say, all over the world, a magnetic needle points nearly north and south. Most persons, probably, are also acquainted with the phenomenon termed the dip or inclination of the magnetic needle: thus, in the latitude of London, a needle exactly poised and freely suspended, instead of assuming a horizontal position, will settle at an angle of 70° to the horizon, the north pole being downwards. If we carry such a needle southward, toward the equator, we observe that the dip gradually diminishes: till at a certain point, nearly coinciding with the earth's equator, the needle has no dip at all, but assumes a perfectly horizontal position. As we still proceed toward the south, the dip again makes its appearance, but in an opposite direction, the south pole of the needle now being downwards. To understand the reason of this dip of the magnetic needle and of its general direction, we have only to consider that the earth itself operates like a great magnet, the poles of which are situated beneath its surface. The directive property of the needle is owing to these poles, and when the needle is on the north side of the equator, the north pole of the earth having the greatest effect, the needle is attracted downwards, toward the north pole; hence, exactly over the magnetic pole, the needle would be vertical. Similar phenomena happen in the southern hemisphere; but here the south pole predominates, and of course, depresses the corresponding pole of the needle: while, at the magnetic equator, from the equal action of both poles, the needle will assume an exactly horizontal position. It may be remarked, that neither the magnetic poles, nor the magnetic equator, coincide exactly with the poles and equator of the earth; and that this non-coincidence is owing to, or rather constitutes, what is termed the variation of the needle, which is not only different in different parts of the world, but appears to be liable, in every part of the world, to periodical differences at present not well understood. Such are the principal phenomena of the magnetic

needle, as demonstrative of the earth's magnetic operation; we shall attempt to illustrate these phenomena a little further.

We have mentioned, that the earth may be considered as acting like a great magnet. Now, we have already shown, that when a magnetic needle is in its natural position of north and south, there exist electrical currents in planes at right angles to the needle, descending on its east side, passing under it from east to west, and ascending on its west side. Hence, we must suppose currents of electricity to circulate within the earth, more especially near its surface, and to be constantly passing from east to west, in planes parallel to the magnetic equator; which electrical currents, if such can be demonstrated to exist, will in their turn completely account for the magnetic directive property of the earth. The next question is, therefore, how far we are justified in assuming the existence of such electric currents within the earth?

In a former chapter we alluded to the phenomena of what has been termed thermo-electricity; that is to say, electricity (and magnetism) developed by the unequal distribution of heat through bodies. Now, whether the phenomena of thermo-electricity actually depend on the decomposition of heat, latent or sensible, or on any other cause, is of little moment; the phenomena themselves are well established; and they seem to account in the most satisfactory manner, for the general distribution of electricity and magnetism over the earth. The explanation is this.

The earth during its diurnal motion on its axis from west to east, has its surface successively exposed to the solar rays in an opposite direction, or from east to west. The surface of the earth, therefore, particularly between the tropics, will be heated and cooled in succession, from east to west, and currents of electricity, on thermo-electric principles, will at the same time be established in that direction: now these currents once established from east to west, will, of course, give occasion to the magnetism of the earth from north to south. Hence the magnetic directive power of the earth, in a direction nearly parallel with its axis, is derived from the thermo-electric currents, induced in its equatorial regions by the unequal distribution of heat

there present, and depending principally on the diurnal motion of the earth.

These observations evidently show, that the operations of nature are more extraordinary, and indicate more of simplicity and wisdom of design in proportion as they are investigated. By what simple expedients, when known, are those wonderful phenomena of the earth's electricity and magnetism produced, which formerly appeared so anomalous and perplexing! And what encouragement do not such discoveries hold out to us, respecting future discoveries, which may allow still further insight into the operations of the Great Architect of the universe!

4. *Of the Distribution of Light over the Earth, in the decomposed Form.*—Every one is acquainted with the general fact, that the most splendid exhibitions of colours of every variety, are seen in the warmer climates; and that the tints of natural objects, generally speaking, become more sad and faded, as we approach the colder regions; till they merge into the white of the polar snows. Most persons, also, are aware of the well-known circumstances attending the total abstraction of light from plants and animals; and that they thus become more or less white, or etiolated. Hence, we need scarcely do more than remind the reader, of what must be already familiar to him, viz., that the decided colours of tropical productions of every kind; whether we consider the gaudy plumage of the birds; or the variegated adornment of the fishes and insects, &c., are so predominant as to be quite characteristic of these climates. In the higher latitudes, also, where the contrast between the summer and winter seasons is very great, the colours of some animals vary with the seasons; being in the summer generally of some dark hue, but in the winter nearly white; while still further in the polar regions, all is more or less white; and the natural covering of the earth, snow, is the whitest body in nature.

Putting out of sight, the great importance of the colours of objects, which will be more appropriately spoken of afterwards; it may be remarked here, that colours have usually been considered as offering to us a striking instance of the benevolence of the Deity. Colours are universally agreeable to mankind; the most incurious and ignorant

being attracted by, and delighted with, showy displays of them. Now, all this pleasure is the gratuitous gift of the Creator; and places his benevolence in the strongest possible point of view. There was no reason why man should have distinguished colours at all, much less have been delighted with them: but what is the fact? not only are we gifted with organs exquisitely sensible to the beauty of colours; but, as if solely to gratify this feeling, the whole of nature, from the highest to the lowest of her productions, forms one gorgeously coloured picture; in which every possible tint is contrasted or associated in every possible manner. Is there a human being who can witness the splendid colouring of the atmosphere above him by the setting sun; who can witness the beauty and endless variety of tint displayed by every object of the landscape around him, down to the minutest insect or flower or pebble at his feet: who is conscious of the pleasure he derives from these objects; and who reflects, that this pleasure was not necessary to his existence, and might have been withheld? Is there, we ask, a human being who duly considers all these things; and who will dare to assert, that the being who made them all is not benevolent?

5. *Of the Laws of Absorption, Radiation, and Reflection of Heat and Light.*—These laws as applied to the earth generally, are at present but very imperfectly ascertained. We shall confine ourselves, therefore, to a simple account of the little we know about them.

The reader will bear in mind what was formerly stated, that the absorbing power of bodies with respect to heat, and perhaps light also, is directly as their radiating power, and inversely as their reflecting power. Such is the general opinion; and, as far as solar heat and light are concerned, this opinion appears to be well founded; but we shall see presently, that there are strong reasons for suspecting, that the radiating power does not always follow the same law, as the absorbing power.

Mr. Daniell has attempted to show, that the absorption, and radiation, of solar heat, increase as we proceed from the equator toward the poles. Thus, in a tropical climate, and under a vertical sun, the greatest extent of the difference between two thermometers, the one covered with black wool,

and exposed to the direct rays of the sun, in order that it may absorb to the utmost the incident heat; and the other, uncovered in the shade, is no more than about 47°; while two thermometers, similarly circumstanced, in the middle of summer, in London, give a difference of 65°; and in the Arctic regions, the difference often amounts to 90° at least: so that in the Arctic regions, there is twice as much heat and light absorbed under similar circumstances, as there is in the tropical regions. The same writer has also attempted to show (what might have been inferred indeed from the assumed relation between the absorption and radiation of heat above stated), that the radiation of heat from the earth's surface obeys similar laws; that is to say, that the quantity radiated from the earth, increases from the equator toward the poles.

Laws somewhat analogous, and which, when they are better understood, will probably throw much information upon these phenomena, seem to hold with respect to light. Thus we formerly mentioned that when a ray of light falls upon fluids, transparent bodies, or metals, the quantity reflected increases with the angle of incidence reckoned from the perpendicular: while the quantity absorbed, of course, decreases in the same proportion: but that on the contrary, when a ray falls upon white opake bodies, the quantity reflected decreases as the angle of incidence increases; while, of course, the quantity absorbed, increases in the like proportion. Hence if heat follow the same law, it is evident that the quantity of heat absorbed by the earth from the solar rays, must increase from the equator toward the poles; that is to say, according to the opinion of Mr. Daniell, as the angle of their incidence increases. It is proper, however, to observe that Mr. Daniell's views have been called in question, and that some late observations made in high latitudes do not entirely corroborate them.*

* We allude here to the observations made in those regions, and given in the Appendix to Captain Franklin's Second Journey, by Dr. Richardson, Captain Back, and Lieutenant Kendal. In these observations Dr. Richardson states that the radiation was much stronger in the spring months, when the ground was covered with snow, than in the summer months, when the altitude of the sun was greatest. Dr. Richardson ascribes this greater radiation to the greater clearness of tho air at these seasons; but were there no other reasons.

There is reason to believe, that the absorption (and perhaps the radiation) of heat and light, under some of its modifications, are much influenced by polarization, and therefore by certain angles of incidence and reflection; and that these circumstances, in consequence, have much to do with the distribution of heat and light, particularly in the higher latitudes.

We have permitted these observations to remain as relating to a subject of great interest to Meteorologists, but requiring elucidation. The phenomena are evidently of a complex character; and before we can form a just estimate either of the separate or conjoint effects of the various causes in operation, the phenomena must be unravelled, and separately investigated. Careful experiments with Sir J. Herschel's actinometer in different latitudes, would doubtless throw much light on certain parts of the inquiry.

In noticing the influence of different colours on the absorption and reflection of heat and light, we stated that black and dark colours generally absorb most and reflect least; and *vice versâ*, that white and light colours, reflect most and absorb least. We now proceed to illustrate this interesting subject, by considering the following questions. Why does whiteness prevail in the Polar regions? Why, for instance, is snow white? On the contrary, why are all sorts of bright and decided colours met with in tropical climates, except whiteness, which is comparatively rare? Might not snow have been black instead of white; which was just as likely if its colour had been the result of accident? or might not whiteness have been predominant under the equator? Perhaps the best mode of answering these questions, and of placing the subject in a striking view, is to examine what would have been the consequence, if whiteness had prevailed under the equator and blackness at the poles.

Since heat and light are supposed to obey nearly the same laws, as far as absorption, radiation and reflection are concerned; it is obvious that if white had prevailed in tropical climates, almost all the solar heat and light there, instead of being absorbed, would have been reflected. The consequenee of this reflection would have been, that the accumulation of heat, and the glare of light, in the lower regions of the atmosphere, near the surface of the earth,

would have beeu quite overcoming; and would have rendered these regions uninhabitable, at least for the present races of animals. The surface of the earth, also, though it would have been heated slowly, would have been overheated in time; and at length would probably have become so very hot, from its comparatively low radiating powers, that the heat could not have been endured. As it is, from the dark colour of objects near the equator, the heat and light of the sun, there, are readily absorbed, and are as freely given off again by radiation; or perhaps the heat, like the light is decomposed; and thus all things are preserved in that comparatively moderate and nicely balanced state, which renders even the hottest parts of the earth's surface inhabitable.

On the other hand, let us consider for a moment, what would have been the consequences, if snow had been black; or in other words, if blackness had prevailed in the Polar regions. In this case, all the little light and heat that reach them, would have been absorbed; and the effect would have been darkness more or less complete. From the rapid melting also of the snow, on the least exposure to heat and light, we should have been constautly liable to inundations. Thus the whole of the Polar regons of the earth, would have been one dark and dreary void, inaccessible to organic life. But by the present arrangement, all these consequences are obviated. The white snow absorbs a certain portiou of light and of heat, (by a beautiful provision, more, as the angle of incidence increases?) while so much light is reflected as is useful, and no more.* Thus the adjustment

* The reader will notice that, under ordinary circumstances, white reflects most, and of course absorbs and radiates least, solar heat and light; but if the above remarks on light be well founded, the absorption of light (and heat?) by white bodies increases with the angle of incidence. Now, as nothing of this sort is known, or can be well conceived to happen, with respect to radiation, the doubt expressed at page 174, arises, viz., whether, under all circumstances, the radiating and absorbing powers of bodies obey similar laws, even as far as the solar rays are concerned. The absorption and radiation of heat of low intensity, and unaccompanied by light, seem to depend more upon the nature of the surface than upon colour. It must be admitted, however, that at present the whole of this subject is involved in much uncertainty.

of the colours of bodies to the circumstances in which they are placed, may be ranked among the finest expedients for obviating those minor incongruities necessarily incidental to the primary distribution of heat and light; and presents altogether one of the most beautiful instances of design, connected with the agency of light and heat.

Lastly, it may be worth while to draw the attention of the reader to the striking contrast displayed between the ponderable and imponderable forms of matter, as to the ease with which they are decomposed, and the modes in which they exist in nature.

We have seen that to preserve the homogeneity and integrity of ponderable bodies, as of water and air, elaborate arrangements have been adopted, evincing the most extraordinary design and wisdom; because the decomposition or derangement of water and air, would at once prove destructive to organized beings. But, to preserve the homogeneity of light, and perhaps of heat also, no such care is shown; because no such care was particularly necessary. The decompositions of these agencies, therefore, are permitted to take their natural course; and by an admirable provision, so far are colours, &c. from being injurious to us; that they constitute some of the chief sources of our knowledge and happiness.

6. *Of the Conduction of Heat below the Earth's Surface on Land.*—The soil, from a few inches to a foot or more below the surface, participates very much in the fluctuations of the surface temperature. In general, perhaps, it may be stated, that the temperature of the surface of the earth, is a little above the temperature of the incumbent atmosphere by day, and below it by night; though much will depend, in this respect, on the nature of the soil; on its radiating and conducting powers; and on a multiplicity of other conditions, which will readily occur to the reader. At a certain distance, however, below the surface, and varying with the latitude and other circumstances, there must be a determinate stratum, where the temperature is uniform, or nearly so, throughout the year. Experiments on this subject appear to show that the temperature of this invariable stratum coincides nearly, with the mean actual temperature of the place; and that its depth below the surface, in

different soils and in different latitudes, varies between fifty and one hundred feet. The reader need scarcely be reminded, that the well known uniformity of the temperature of cellars and caves, depends chiefly on the two circumstances we are now considering. As an instance of the uniformity of temperature in such places, it may be mentioned, that a thermometer placed in the caves under the observatory in Paris, at a depth of about eighty-five feet below the surface, has, during fifty years, scarcely varied more than a quarter of a degree from 11·82° of the centigrade scale; equal very nearly to $53\frac{1}{4}°$ of Fahrenheit.

A few experiments have been made to determine the variation of temperature, throughout the year, at different depths from the surface, down to the invariable stratum; and the following is a summary of the results, which, perhaps, may be considered as generally applicable to the northern hemisphere.

In the month of August, the temperature of the earth decreases, in nearly a uniform manner, from a little below the surface, to the stratum of invariable temperature. In the month of September, the temperature is nearly uniform to fifteen or twenty feet below the surface; beyond which depth, the temperature decreases a little and slowly, to the stratum of invariable temperature. During the months of October, and November, the temperature increases from the surface, to the depth of fifteen or twenty feet; and below this depth, it remains nearly uniform to the invariable stratum. During December, January, and February, the temperature, being at its minimum upon the surface, increases in a manner nearly uniform, downwards to the invariable stratum. During March, and April, there is a rapid decrease of temperature to the depth of one or two feet; below this depth, the temperature decreases less rapidly; and still lower, the temperature increases a little. During the months of May, June, and July, the temperature being at its maximum, at the surface, decreases downwards, but less rapidly and to a greater depth; it then begins to increase a little, till it attains the temperature of the invariable stratum. The rapidity and degree, however, with which these changes take place, as well as the changes themselves, appear to fluctuate very considerably, not only

in different places under the same Isothermal line, but in the same place in different seasons.*

Since heat passes through the soil by conduction, it is of course extended in all directions: so that heat may be supposed to move laterally as well as downwards; and, generally speaking, the temperatures of contiguous spots probably tend to equalize each other. But on the whole, the influence of the lateral extension of heat through the solid parts of the earth must be very limited.

7. *Of the Extension of Heat and Light below the Earth's Surface in Water.*—Water is a very imperfect conductor of heat, in the usual acceptation of the term. Thus, almost any degree of heat may be applied, for a considerable time, to the upper surface of a mass of water, without materially influencing the temperature below; so imperfectly and slowly is heat conducted through this fluid. The process by which heat is communicated through water, we have termed convection. When heat is applied to the bottom of a vessel full of water, the portion of the water first heated, expands in bulk, and thus becomes specifically lighter; it then rises to the top, carrying with it the newly acquired temperature; while another cold portion, sinking to the bottom, is heated in turn: and so on, till the whole mass becomes uniformly heated.

With respect to the passage of light through water, it has been calculated, that not a tenth part of the incident light, can advance five fathoms downwards in the most translucent water; that even of vertical rays, one half is lost in the first seventeen feet; and that these vertical rays become reduced to one-fourth by traversing thirty-four feet, which correspond to the mass of an atmosphere. It thus follows that only the hundred-thousandth part of the vertical rays, can penetrate below forty-seven fathoms; which is scarcely equal to the glimmer of twilight; and that the depths of the ocean must be always in perpetual darkness.†

Such are the general principles according to which heat

* The time required for the passage of heat one foot downwards, has been found to vary under different circumstances of soil, &c., from four to seven days.

† Article "Climate," in the Encyclopædia Britannica.

and light pervade water. But in speaking of this fluid in a former chapter, we alluded to one of the physical properties of water, of the utmost importance in the economy of nature, and which, perhaps, almost more than any thing else, indicates design; since, like the composition of the atmosphere, this property of water constitutes an exception, as it were, to a general law, expressly directed to a particular object.

We have mentioned the general law, that all bodies, in every state of aggregation, expand by heat and contract by cold: now water forms a marked exception to this law. Like other bodies, water continues to contract on the removal of heat, till its temperature descends to within a certain distance (7° or 8°) from its freezing point. At this distance, water begins again to expand, and the expansion continues till it becomes ice; at which moment of freezing, a sudden and considerable expansion takes place. Hence, the specific gravity of ice, is decidedly less than the specific gravity of water, and the solid necessarily swims on the surface of the fluid.

The importance of this anomalous property of water is so great, that it is doubtful whether the present order of nature could have existed without it; even although every thing else in the world had remained the same. For instance, were it not for the comparative lightness of ice, this solid, instead of beginning to be formed at the surface of water, would have begun to be formed at the bottom, as the colder water from its greater specific gravity, would naturally have sunk; for similar reasons also the lowest stratum of ice would have been the last to have melted. Now, let us reflect for a moment on the consequences of such an arrangement. In the northern, and even in temperate climates, the bottoms of all lakes and deep waters would have been a mass of ice, and totally inaccessible, therefore, to organized beings. During the summer, a few feet of the upper part of the ice would, perhaps, have been melted; but what little had thus been melted in summer, would again have become solid during winter; and as the accumulations of ice would have been constant, all the seas, even perhaps to the tropical climates, at least at their bottom, would long before this time, have been a mass of ice! But

what in reality happens? In consequence of the above anomalous properties of water, this mischief is entirely prevented, and not a particle of ice can be formed in a lake or other collection of water, till the whole mass is cooled down to the temperature of 40°, at which temperature the specific gravity of water is at its maximum.

These properties of water operate in the following manner. On the application of cold to the surface of water, the cooled portion sinks, and its descent forces up a portion of warmer water to the surface, which after communicating some of its heat to the superincumbent air, sinks in its turn; and this process goes on for a greater or less time according to the depth of the water. If the depth be not very considerable, the whole body of the water becomes cooled down to 40°; at which temperature the specific gravity not increasing, the circulation ceases; and the surface of the water (not the bottom) becomes at length so far cooled as to be covered with ice. If the depth of the water be considerable, the application of cold may be long continued without the result of freezing; hence, in this, and in other countries not intensely cold, it often happens that deep lakes remain unfrozen during the coldest winters.

The above anomalous properties of the expansion of water and its consequences we have always viewed as presenting the most remarkable instance of design in the whole order of nature—an instance of something done expressly, and almost (could we indeed conceive such a thing of the Deity), at second thought, to accomplish a particular object. Further, if in conjunction with this anomalous property of water, we take into account the still more anomalous constitution of atmospheric air, and at the same time consider the relations of water and air to organic existence, we are unavoidably impelled to the conclusion, that the Maker of water and of air has designedly created these anomalies to obviate difficulties which would have rendered organic existence a physical impossibility. Nor do the suppositions which the sceptic will urge, that these properties of water and air flow naturally from their constitution, diminish the force of the argument. The force of the argument lies, in the first place, in the fact, that water and air have been created with such anomalous properties;

and, in the next and chief place, that these anomalous properties have been brought into action precisely where they are required. Moreover, the argument is greatly strengthened by the fact that two anomalies, rather than that two ordinary circumstances, have been thus expressly adjusted.

Having stated the general principles on which heat is distributed through water, and its most remarkable consequence, we are now to enter into a few details with respect to some other consequences of this distribution. Of these consequences one of the most striking is, that the temperature of the water at the bottom of deep lakes, or inland seas, must remain nearly uniform during the whole year. Thus it has been found, that the temperature of the water, at the bottom of many of the lakes in Switzerland, often varies no more than 3° or 4°, while the temperature of the surface often fluctuates 20° or 30°. Hence in deep waters, in temperate climates, the changes of temperature are chiefly confined to the upper strata of the water; nor can ice (except from some very sudden and powerful accessions of frost) be formed on the surface of such a lake, till, as before observed, the whole of the water in it is cooled down to 40°, at which temperature all circulation ceases. When a coat of ice has been once formed, this ice, as we shall see presently, has also a powerful tendency to prevent the further cooling of the inferior strata.

With respect to waters in motion, as small streams, or rivers of no great depth and magnitude, and containing fresh water, though unfavourably circumstanced for freezing, they do nevertheless congeal. The process usually commences at the shores, where the water is shallowest, and its motion is least rapid, from whence the ice gradually advances toward the middle of the stream. When the whole of the surface has once become fixed, congelation goes on actively, particularly by night. As the thickness of the ice increases, however, the quantity added daily, even supposing the cold to remain the same, gradually diminishes on account of the bad conducting power of ice. Hence, in a block of ice taken from a river or lake, we may often observe the strata corresponding with the daily, or rather

nightly additions, presenting a gradually decreasing series from several inches down to a few lines in thickness.

Of the Temperature of the Waters of the Ocean at great Depths.—Between the Tropics, the temperature of the ocean diminishes with the depth; in the Polar seas, on the contrary, the temperature augments with the depth. In the temperate seas, comprised between 30° and 70° of latitude, the temperature of the water gradually decreases as the latitude increases, until about the latitude of 70°, where the temperature as compared with the latitude begins to rise. Hence, about the latitude of 70°, there exists a zone or band at which the mean temperature of the ocean is very nearly constant at all depths. The temperatures of particular parts of the ocean, however, have been observed to be much influenced by the depth and extent of the water, particularly in high latitudes.

We have already mentioned the influence of the saline matters of the ocean on the freezing point of sea-water, and we now direct attention to the important consequence of this property in the economy of nature. In its natural state, sea-water freezes at about 28° or 29°; but when it has been concentrated by previous freezing, the congealing point is reduced to 15° or 16°, while water saturated with salt does not freeze at a temperature above 5°. Besides this property of lowering the freezing point of sea-water, the saline matters also increase its specific gravity, and affect its point of maximum density. From these circumstances, and from the immense depth and extent of the waters of the ocean, they resist freezing still more effectually than even running fresh water, and are indeed rarely frozen, except in latitudes where the most intense and unremitting cold prevails.

Of the under Currents of the Ocean, existing between the Equatorial and the Polar Regions.—That the diminished temperature of the ocean, at great depths, near the equator, could not have been acquired in the torrid zone is evident: nor, on the other hand, could the comparatively high temperature of the waters, at the bottom of the Polar seas, have been acquired in the frigid zone; at least this high temperature of the Polar seas, cannot be caused from

without. Hence it has been supposed, that there is a constant interchange going on between the waters of the Equatorial, and the waters of the Polar regions; though there are considerable difficulties, at present, as to the means by which this interchange is effected. These difficulties arise principally, from some uncertainty, with respect to the point of maximum density of sea-water, which does not appear to be satisfactorily established. Whether in the profound, and comparatively quiescent abyss of the ocean, the process of diffusion, or the central heat of the earth formerly alluded to, exerts any influence, we have no means of determining. But if a central heat really do exist, its effects must be considerable, particularly within the frigid zone. Whatever be the cause of this approach to uniformity of temperature throughout the waters of the ocean at great depths, all over the globe; its use in the economy of nature, in tending to equalize the distribution of temperature, cannot be questioned; since it constitutes one of those beautiful provisions, by which the impediments to the distribution of temperature, necessarily incidental to the earth's figure and motions, are obviated: whilst among the minor circumstances contributing to the same end, may be mentioned the tides, and the innumerable superficial currents produced by winds, and by other causes, which are to be considered elsewhere.

8. *Of Differences of Temperature, depending on whether the Surface be Land or Sea.*—When speaking of the distribution of temperature over the earth's surface, we alluded to the differences between insular and continental climates. Here, therefore, we may appropriately notice the actual general amount of the differences of temperature, as produced by land and water.

In the middle of oceans, and far from the influence of land, the diurnal change of temperature of the air near the surface of the sea, is much less than on land. Thus, in the equatorial regions, the greatest difference between the temperature of the day and the temperature of the night, at sea, is said to amount to 3° or 4° only; while upon land the difference often amounts to 9° or 10°. In temperate regions, and particularly in latitudes extending from 25° to 50°, the difference between the maximum and the minimum

diurnal range of the thermometer, at sea, is still very trifling, amounting only to 4° or 6°; while upon the continents, as for example, at Paris, the range often amounts to 20° or 30°. To these circumstances it is owing, that small insular situations, partaking of the character of the surrounding ocean, are much less liable to great diurnal changes than continents; and hence, in general, they possess more equable climates.

Both at sea and on land, the minimum temperature takes place about sunrise. The maximum temperature at sea occurs about noon, or very soon after; while on land, it takes place from two to three hours after noon. Between the tropics, the maximum temperature of the air is said to exceed a little that of the surface of the sea. But when the temperatures are observed at short intervals, as for example, every four hours, and all the temperatures are compared, the results are different; and they seem to show, that even between the tropics, the temperature of the surface of the sea is higher than the temperature of the incumbent atmosphere. Between the latitudes of 25° and 50°, the air is rarely warmer than the surface of the sea; and in the Polar regions, it is very unusual to find the air as warm as the sea; it is in fact almost always colder, and generally very much colder.

As connected with this part of our inquiry, it may perhaps, before we close, be desirable to offer a few remarks on the temperature of natural springs, and their relation to the mean temperature of the earth, at the places where they make their appearance.

Springs discharging large quantities of water, and thus indicating that they come from considerable depths below the surface of the earth, preserve nearly the same temperature during the whole year. In our hemisphere, what little augmentation of temperature springs undergo, is generally in the month of September, while they are coldest in the month of March; though the differences seldom exceed two or three degrees.

If we compare the temperature of the springs of any place, with the mean annual temperature of that place; we find that there is a near connexion between the two, all

over the globe. In the torrid zone, however, the mean annual temperature of the air is usually higher by three or four degrees than that of the springs; while in the temperate zone, on the contrary, the springs are warmer than the air. The excess of temperature of springs, as compared with the mean annual temperature, goes on increasing with the latitude; so that, between 60° and 70° of latitude, this excess amounts to from 5° to 7°. Other things being the same, the temperature of springs varies considerably, according to their copiousness; as a large body of water will be less liable to be influenced by the surrounding soil, than a smaller body of water; and may even, in turn, influence the temperature of the soil itself.

The subject of thermal springs, as intimately connected with the history of volcanoes, belongs to the Geologist.

We have thus enumerated the principal circumstances connected with the distribution of temperature upon the surface of the earth, and at such parts below the surface as are within our reach. We now come to the second great division of the subject of climates; viz., climate as depending on the atmosphere.

§ 2.—*Of the Secondary Constituents of Climate immediately connected with the Atmosphere.*

The phenomena of the atmosphere, originally constituted the proper study of the Meteorologist, and even yet these phenomena claim the largest share of his attention. The subject, in all its bearings, is very extensive, and many of the details are imperfectly understood. We shall endeavour to present a brief outline of the principal phenomena under the following heads.—Of the distribution of heat and of light through the atmosphere, and of the consequences of that distribution;—of the distribution of water through the atmosphere, and of the phenomena dependent on that distribution; and, lastly,—of the occasional presence of foreign bodies in the atmosphere.

1. *Of the Distribution of Heat and of Light through the Atmosphere, and of the Consequences of that Distribution.*—Every one is familiar with the general fact of the diminished temperature of the higher regions of our atmosphere: and

that in the hottest countries, by ascending a lofty mountain, we encounter, at different heights, every variety of temperature, even to the temperature of perpetual snow, and of the Polar regions. One of the first circumstances, therefore, which claim the attention of the Meteorologist, is the law of the distribution of sensible heat, or of temperature, through the atmosphere.

The law of the distribution of temperature through the atmosphere is tolerably uniform: though it is occasionally liable to variations and interruptions, depending on local differences; and perhaps on other circumstances not satisfactorily ascertained. The mean results of a great number of observations, made in different parts of the world, appear to show, that for every 100 yards of altitude Fahrenheit's thermometer sinks one degree. This statement, probably, does not, within moderate limits, differ much from the truth; though some late researches have rendered it probable, that while at different heights the rate of the decrease of temperature is uniform, the rate of altitude increases constantly, and according to laws very similar all over the world; that is to say, supposing the first 252 feet are equal to one degree; the second degree will be equal to 255 feet; the third to 258; the fourth to 261; &c.

The causes on which this great cold of the higher regions depends, are chiefly the two following; first, the perfect permeability of the atmosphere to the solar rays; on which account the rays of the sun radiate through the atmosphere almost without affecting its temperature, till reaching the earth, the rays exert their utmost influence; and secondly, the increased capacity for heat possessed by air, in proportion as it becomes more rare. From the first of these causes it happens, that the temperature of the lower regions of the atmosphere is derived, not immediately from the sun, but from the earth. The surface of the earth absorbing the solar heat, recommunicates that heat to the immediately incumbent atmosphere; while all the higher portions of the atmosphere remain unaffected. For though, from diminished specific gravity, heated air naturally ascends, yet as its capacity for heat at the same time increases, ascending air rapidly loses its sensible heat: as in the second place we have to explain.

London, H.G. Bohn

Dr. Dalton, and afterwards Sir John Leslie more completely, have attempted to show, that the equilibrium of heat in an atmosphere, is obtained, when each of its molecules, or in other words, when the same weight of air, in the same perpendicular column, is possessed of the same quantity of heat. Now, since atmospheric pressure diminishes with the height, according to a certain law; it is obvious, that the same weight of air, at the surface of the earth, and in the higher regions, will occupy very different spaces. But since the absolute quantity of heat is exactly the same in both portions; it is likewise obvious, that in the higher regions of the atmosphere, from the increased capacity of the air for heat, the quantity of latent heat is augmented, while the quantity remaining sensible, becomes less. Hence the temperature of the air diminishes as we ascend, exactly in the proportion its latent heat, that is to say, its capacity for heat as produced by rarefaction, increases. In consequence of this arrangement, to use the words of Dr. Thomson, "if a quantity of cold air were suddenly transported from an elevated region to the surface of the sea, its density would be continually increasing during its descent, while its latent heat would diminish in the same proportion; and when it reached the level of the sea, its temperature would be just as high as that of other portions of air in the same latitude and elevation. Air, therefore, does not feel cold in consequence of falling from an elevated situation, though this be an opinion commonly entertained; but in consequence of its being suddenly transported from a more northerly, to a more southerly situation."* Thus, to the above beautiful and simple law, we owe the permanent state of equilibrium of temperature in the atmosphere; which equilibrium, in spite of all the disturbances constantly produced by minor causes, from the natural tendency to right itself, is never very seriously affected.

Of the Limits of Perpetual Snow.†—Connected with diminution of temperature in the higher regions of the atmosphere, are the limits of perpetual snow in different latitudes. These limits, of course, may be naturally supposed to follow the mean temperature of 32°, from the

* On Heat and Electricity, p. 129.
† See Appendix and Map.

level of the sea in the Polar regions, to the highest point of their range under the equator. This inference is obvious, and, generally speaking, correct; though it is liable to certain modifications, and to some anomalies, of which the following are the most remarkable.

Under the equator, the limits of perpetual snow are the most fixed and steady, and seem to exist generally at an altitude of between 15,000 and 16,000 feet. As we recede from the equator, the oscillations for the most part become more striking, and all the phenomena assume a more irregular character. Such, for example, is the case in the Mexican Cordilleras; but still more evidently in the Himmala* range; where there is a difference of no less than 4,000 feet, between the limits of perpetual snow on the northern, and on the southern sides of the mountain; the snow line being highest on the northern side.† As we proceed toward the temperate zones, we find, in mountainous countries, below the limits of perpetual snow, immense bodies of ice, or glaciers, as they are termed. These glaciers are formed by the alternate melting and congealing of the extensive beds of snow that lie above them. The glaciers accumulate in valleys, and often by the enormous and increasing weight of the snow and ice in the upper parts, are pressed downward far beyond the limits of the snow itself. Such are the glaciers of Switzerland, of Norway, and of other countries in temperate climates. All these circumstances, with others which might be stated, and many probably that are unknown to us, combine to render the limits of perpetual snow irregular. These irregularities are so considerable, that Humboldt, from numerous observations, has inferred the limits of perpetual snow at the equator to be nearly 3° above the freezing point; while in the temperate zone, the snow limit is nearly 5° below that point; and in the frigid zone, no less than 10° or 11° below freezing; results which seem to prove, that the general

* (Or Himalaya.)—G.

† This great difference between the limits of perpetual snow on the northern or the southern sides of the Himmala range, is due to the changes of the monsoons. The monsoons, from the extensive plains on the north of the range, are much warmer than the monsoons from the south, which partake of the character of sea breezes.

temperature of the air decreases in the equatorial, otherwise, than in the colder regions. From the peculiar distribution of the land in the southern hemisphere, little is known of the line of perpetual snow in that part of the world; but it will probably be found to be different from the line in the north, and generally lower.

The perpetual snow resting on the tops of mountains, constitutes a most important provision in the economy of nature, particularly in the warmer climates, where the accumulated snow becomes the prolific source of innumerable rivers, without which those regions would be uninhabitable.

In the accompanying map, we have endeavoured to show the analogy between the effects produced on the distribution of temperature, by height above the surface of the earth, as compared with difference of latitude. There is, however, one striking difference between high and low situations, which must have considerable influence upon organization, though this influence has not been studied so carefully as it ought to be; viz., the difference of atmospheric pressure. At the surface of the earth, the atmospheric pressure is nearly the same in all latitudes; but as we ascend above the surface, the pressure rapidly diminishes. Every thing else, therefore, being supposed to be the same, the difference of pressure will probably render certain provisions and accommodations necessary, of which, at present, we are ignorant; but which might doubtless be much elucidated by a careful study of Alpine plants and animals, as compared with those occupying the plains. Another circumstance, which must materially influence organization, is the great intensity of light in the mountainous districts of tropical climates, as compared with the intensity of light at the surface of the earth, in the corresponding climates of high latitudes. The diminished intensity of light, however, in high latitudes, is doubtless compensated for, in some degree, by the greater length of the day.

Of the Distribution of Heat and Light through the Atmosphere in their latent Forms.—In the preceding paragraphs, we have alluded to the quantity of heat existing latent in the higher regions of the atmosphere. But be-

sides this quantity, which may be supposed to be common to the whole atmosphere; the distribution of latent heat and light must follow nearly the same law as the distribution of sensible heat and light; that is, must decrease from the equator towards the poles. Thus there can be no doubt, that the expanded air of the equatorial regions, contains much more heat and light in the latent state, than the comparatively dense and dry atmospheric air of the Polar regions; and it is probable that the rigours of each extreme are mitigated by this provision. The distribution of electricity through the atmosphere, seems also to be regulated by very similar laws. It may, however, be remarked, that the effeets of heat and light, in the latent form, as well as the effeets of electricity, are much more evident than from their connexion with the water in the atmosphere, than from their eonnexion with the constituents of the atmosphere itself. We shall, therefore, defer what we have to say on those subjeets, till we speak of the water in the atmosphere.

Of the Distribution of Sensible Heat through the Atmosphere.—The distribution of sensible heat through the atmosphere is chiefly effected by the proeess termed eonveetion. Convection, of course, implies motion, or currents; which currents pervading the atmosphere, we need searcely observe, are denominated Winds. The winds, therefore, are of the utmost importance in the economy of nature, from their tendency to equalize the distribution of temperature over the globe: the following brief explanation will serve to give a general knowledge of their nature.

Atmospherie currents may be considered under two heads: currents of a general kind, extending more or less over the whole globe; and currents which are produced by various transient derangements of the distribution of temperature, the effects of which are limited to partieular localities. On each of these two kinds of currents we shall make some remarks.

The general currents of the atmosphere depend principally on the two following circumstances, which, if borne in mind, will furnish the reader with a clue to the whole subject, viz., the unequal temperature of the equator and of the poles; and the diurnal motion of the earth on its

axis. The convective operation of the first of these general causes may be thus illustrated. We have stated that the entire pressure of the atmosphere all over the earth's surface is nearly the same, and equal to the pressure of a column of mercury about thirty inches in height. We have also stated that the mean temperature of the atmosphere near the equator, and at the level of the sea, is upwards of 80°; while in the Polar regions, the mean temperature is constantly below 32°, the freezing point of water. Hence, as air expands by heat, and becomes specifically lighter; it is obvious that a given bulk of air at the level of the sea round the poles, must be considerably heavier, than a similar bulk of air at the level of the sea under the equator. The air, therefore, round the poles being colder and heavier, will have a tendency to flow along the earth's surface from the poles toward the equator, and to displace the lighter air at the equator; while the equatorial air so displaced, will, owing to its lightness, ascend and flow back again over the colder air, north and south toward the poles, so as to preserve the equilibrium. Moreover these currents will be perpetual; for the heat of the equator and the cold of the poles being constant, the same tendency to change will always exist, and thus the currents will be constant likewise.

These atmospheric currents form one primary constituent of the winds; and are the grand means by which the equalization of temperature over the globe is effected. If the earth were at rest, and free from irregularity, the currents or winds near its surface would, of course, be in the northern hemisphere, always due north; and in the southern hemisphere, due south; while the velocity would in each case, gradually diminish from the poles toward the equator; where there would be a perpetual calm.

But the earth is in a constant state of motion on its axis, from west to east; by which motion, the aërial currents are deflected from their northern and southern course toward the east. This eastern deflection forms the other primary constituent of the winds, to be next considered.

The general reader will bear in mind; that on the surface of a globe, revolving like the earth on its axis the motion of any given point at the equator, is the greatest,

and at the poles, the least possible. Thus while the poles are quiescent, the velocity of any given place at the equator of our earth, is about 1000 miles an hour; from which extreme the velocity gradually diminishes toward the poles. This motion of the earth on its axis, operates in the production of an easterly current in the atmosphere, as follows. Supposing there were no atmospheric currents from the north and south toward the equator, and that the earth revolved on its axis as at present; one of two things must happen. Either the earth during its revolution would carry with it the incumbent atmosphere; in which case there would be a perpetual calm over its surface; or the earth would revolve within the atmosphere, leaving, as it were, the atmosphere behind it; in which case there would be an apparent current or wind over the whole of the earth's surface, in a direction opposite to the direction of the movement of the earth, that is from east to west; which wind, supposing the atmosphere did not move with the earth, would, of course, be at its maximum at the equator. Now both these causes are continually operating, and give origin to all the variety of the eastern currents upon the earth's surface; which, with the northern and southern currrents, before described, conspire to produce the well known currents, called the trade winds. Before we attempt to explain the trade winds, their phenomena may be thus briefly described.

The trade winds in the Atlantic ocean, extend to about 28° on each side of the equator. At their extreme northern and southern boundaries, these winds generally blow from the east: but as they proceed toward the equator from the north and from the south, they gradually pass from the east, through all the intermediate points of the compass: till near the equator, they become in the northern hemisphere, due north; and in the southern hemisphere, due south. The trade winds are also subject to some slight variations chiefly arising from the position of the earth with respect to the sun. On these variations we do not think it necessary to enlarge. The general phenomena are as stated; and the principles we have advanced, appear to offer the following explanation of these phenomena:

In the temperate regions of the earth, the winds seem

to obey no certain laws; at least, no laws so determinate as those of the trade winds. But about the tropics, both in the northern and southern hemispheres, the operation of the double currents and motions before described, becomes distinctly perceptible. Thus about the tropics, the surface of the earth begins to move faster than the incumbent atmosphere; and hence in these regions, the prevailing currents are from the east. Indeed near the tropics, the currents are almost due east; principally on account of the great and somewhat sudden change of temperature produced by the vertical sun of the tropical regions; which may be supposed to intefere with, and perhaps to check momentarily, the regular progress of the great northern and southern currents. As we proceed, however, toward the equator: the atmosphere, in both hemispheres, gradually acquires the velocity of the earth; while the intensity of the eastern current, diminishes in the same proportion, and at length entirely disappears. At the same time, the currents from the north and the south continuing, slowly deflect the currents, from the east toward the north, in the northern hemisphere; and from the east toward the south, in the southern hemisphere; till left alone by themselves, the polar currents proceed onward to the equator, as if the motion of the earth had no existence.*

To these great atmospheric currents may be traced the fluctuations of the barometer, and all the innumerable modifications peculiar to different localities of sea and land, of mountain and plain. For, as Mr. Daniell justly observes, in the nicely balanced state of the forces producing these currents, slight irregularities of temperature are capable of causing great disturbances; and expansions and contrac-

* In the first edition of this volume, we ascribed the above theory of the trade winds to Mr. Daniell. We have since learnt, however, that the same theory was advanced a century ago, by Mr. Hadley. (Philos. Trans. xxxix. p. 58.) Without being aware of the existence of Mr. Hadley's paper, Dr. Dalton offered a similar explanation of the trade winds in his Meteorological Observations and Essays. Subsequently, the theory was reproduced by Mr. Daniell, and illustrated by Captain Basil Hall, in an appendix to the second edition of Mr. Daniell's Meteorological Essays; to which we refer the reader for a detailed account of the phenomena of the trade winds.

tions acting unequally upon the antagonist currents, operate by deranging the adjustment of their several velocities. Hence accumulations in some parts, and corresponding deficiencies in others, necessarily arise; and occasion fluctuations in the barometer, far surpassing what would be occasioned by the whole vapour, supposing it were at once added, or annihilated. At the same time, these irregular distributions, in struggling to restore the equilibrium, produce temporary and variable winds, which modify the regular currents, and often reverse their courses, particularly in the temperate regions; where, as formerly mentioned, the alternations of temperature, and the fluctuations of the barometer, are the most remarkable.

Such are the general currents pervading our atmosphere; and by such modes do these currents modify extreme temperatures and their consequences. The same causes are continually operating in different forms and degrees; so as to produce all that infinite variety among the winds, which we observe in nature. These are so numerous and diversified, as actually to baffle all attempts at explanation or arrangement; we shall therefore content ourselves with one instance only, by way of illustration, viz., the sea and the land breezes.

The explanation of what are denominated the sea and the land breezes is very obvious; and is not less applicable to many similar phenomena. During the day, the surface of the land acquiring heat, imparts its temperature to the incumbent air. This air expanding in bulk becomes specifically lighter, and rises in consequence; while the cooler air from the surrounding sea rushes in to supply its place, and thus produces the current called the sea breeze. During the night, on the contrary, the waters of the ocean part with their heat much more slowly than the land, and the reverse action, or the land breeze, takes place. In hot climates near the sea-shore, and in insular situations, these alternations constitute a most agreeable variety.

2. *Of the Presence of Water in the Atmosphere.*—In the foregoing section, we have endeavoured to give an outline of those beautiful provisions, which, by means of the air of the atmosphere, have been adopted to prevent the consequences necessarily arising from the unequal distribution of

heat and light over the globe. We now come to another subject of not less interest, viz., the phenomena depending on the existence of water in the atmosphere; and which, taken together, principally constitute what we emphatically denominate the Weather.

The phenomena arising from the existence of water in the atmosphere may be considered under the four following heads:—First, Of the phenomena of evaporation and condensation; and of the general dependence of vapour on temperature:—Secondly, Of the conditions of an atmosphere of vapour alone; and of a mixed atmosphere of vapour and air:—Thirdly, Of the general relations of evaporation and condensation, as they exist in our atmosphere; and of the circumstances by which these relations are influenced:—Fourthly, Of the distribution of heat and light in their latent and decomposed forms, through the vapour of the atmosphere; and of the effects of that distribution.

First, *Of the phenomena of evaporation and condensation; and of the general dependence of vapour on temperature.*—We have before stated the fact, that water assumes the elastic form, in a greater or less degree at all temperatures. From the tendency of water, thus to rise "above the Firmament;" not only the ocean, but ice and snow, are unceasingly contributing their supply of moisture to the air; and this fluid, so indispensable to vegetable and animal existence, is distributed over the surface of the whole earth. In considering, therefore, the relations of the water of the atmosphere to temperature; the phenomena which first claim our attention, are the processes by which water is taken up, and again separated, from the atmosphere; that is to say, the processes of Evaporation and Condensation.

In treating of the nature of Evaporation, the questions to be answered at the outset are,—Why is moisture present in the atmosphere? By what force is its presence determined, and its quantity limited? The reply to these questions depends on the properties of matter in general, and of vapour in particular, as formerly described. These properties, if borne in mind by the reader, will enable him to understand what follows.

When water is exposed to the air in an open vessel, the molecules of its uppermost or superficial stratum being

released from the influence of the molecules below them, have a natural tendency to assume that degree of polarity which is appropriate to their temperature. Hence, after acquiring the latent heat necessary to produce this polarity, either at the expense of a portion of their own sensible heat, or of the heat of the atmosphere; the superficial molecules of water become self-repulsive, and fly off into space in the form of vapour. If the space over the water be circumscribed and be a vacuum; the molecules fly off with such rapidity as instantaneously to fill it. But, if the space be occupied by air, or be of indefinite magnitude; the molecules fly off more slowly, so as gradually to diffuse themselves through the whole space; quite on the same principle, and in the same manner, that one gaseous body is diffused through another gaseous body.

Such, in a few words, may be deemed a simple statement of what evaporation is. We have next to inquire into the nature and operation of the means by which evaporation not only takes place, but is limited within certain boundaries.

In a former chapter, we showed, that the elastic force exerted by all bodies in the gaseous state, bears a certain relation to their temperature; but that the degree of this elastic force varies according to other circumstances; particularly, according to whether the gaseous body, at the given temperature, be capable of existing in the fluid or in the solid states, as well as in the gaseous state. Thus, atmospheric air, not only at the temperature of 32°, but at all known temperatures, is a gaseous body; and, under ordinary circumstances, exerts an elastic force equal to the weight of a column of mercury 30 inches high: whereas, at the same temperature of 32°, water is a solid; and the force of the elasticity of its vapour, is not more than equal to about 1-5th of an inch of mercury. But at and above 212°, its boiling point, water, under ordinary circumstances, can exist only as a gas; and in this gaseous form, and at the temperature of 212°, water obeys precisely the same laws, and exerts the same elastic force, as atmospheric air would obey and exert under similar circumstances. Hence it will be readily understood, that the law of the elastic force of vapour below 212°, is very different from the law of that force above 212°: as by experiment is found to be the fact.

From this relation of elastic force to temperature, all other things being the same, the tendency of water to assume the form of vapour, or the rate of its evaporation, as well as the actual quantity of water in the state of vapour in the atmosphere, will increase as the temperature increases. We need not state in detail, the exact law of this increase. It is sufficient for our purpose to observe, that at all temperatures below the boiling point of water, that is to say, at all common atmospheric temperatures: while the rate of the increase of temperature is slow and uniform, or in an arithmetical progression; the corresponding rate of the elastic force of vapour, by which the quantity of water as vapour is determined, increases much more rapidly, or nearly in a geometrical progression; a fact connected with several most interesting circumstances.

The phenomena of the Condensation of vapour from the atmosphere, are next to be explained. As the quantity of water in solution in the atmosphere, can never be greater, though it may be less, than the quantity proper to the temperature of the air; when vapour, or what is the same thing, when a portion of air saturated with vapour, at any given temperature, is cooled below the point of saturation; a portion of the vapour is separated from the air in the form of liquid water, while the remainder assumes the elastic condition proper to the newly acquired and diminished temperature. The forms assumed by the water so separated, are various; and depend very much on the quantity separated; and on the separation taking place in atmospheric air. When the quantity of water separated is small; the minute detached globules diffused through a large space are suspended in the atmosphere by its buoyancy, and assume the form of what, for the sake of distinction, we shall call Visible Vapour, viz. mists, clouds, &c. When the quantity of water separated from the air is greater; the globules collect into drops too large to be upheld by atmospheric buoyancy, and they fall to the earth in the shape of rain, hail, and snow.

Of the two great processes of evaporation and condensation, it may be further remarked, that by a beautiful provision, they have a constant tendency to limit each its own operations: evaporation is increased by heat and produces

cold; condensation is produced by cold, and liberates heat. Moreover, in virtue of another wonderful arrangement; by evaporation, water is separated entirely from all foreign bodies, and is thus condensed in a state of absolute purity.

Secondly, *Of the conditions of an atmosphere of vapour alone: and of a mixed atmosphere of vapour and air.*—We now proceed to consider more particularly the mode in which vapour exists in the atmosphere. To facilitate the understanding of the subject, we shall commence by supposing the air to be absent; and shall inquire what would be the conditions of an atmosphere of vapour under the pressure and temperature existing at the surface of the earth, and at different heights above the earth's surface.

Since the elastic force of vapour increases faster than the temperature of the vapour; and since the mean temperature at the Equator is, at least, 80°, while at the Poles the mean temperature is below 32°; it follows that in an atmosphere of vapour, heated similarly to the atmosphere of our earth, the specific gravity of the vapour at the Equator, would greatly exceed the specific gravity of the vapour at the Poles. Vapour thus exhibits a condition directly opposite to the condition of air, under the same circumstances. Hence the tendency of lateral currents, in an atmosphere of vapour, at the surface of the earth, would be precisely the reverse of the tendency of lateral currents in an atmosphere of air; the tendency of vapour currents would be from the Equator toward the Poles; instead of, as in air, from the Poles toward the Equator.

We have elsewhere stated the law of the decrease of the temperature of the atmosphere, observed in ascending from the surface of the earth; the atmospheric air being supposed to be free from moisture. A similar law would regulate the decrease of temperature in an atmosphere of vapour; but the rate of decrease would be much more slow, than in an atmosphere of perfectly dry air. Thus under the Equator, where, at the level of the sea, the mean temperature is at least 80°; the temperature of an atmosphere of perfectly dry air would sink to the freezing point at a height of 15,000 feet: while the temperature of an atmosphere of vapour would, at the same height, sink only to 70°. At all the parallels of lower mean temperature,

onward to the lowest mean temperature round the Poles, at any height above the level of the sea, similar differences would exist between the temperature of an atmosphere of perfectly dry air, and the temperature of an atmosphere of vapour; these differences, of course, varying with the mean surface temperature. At the same time, throughout the whole range, from the Equator to the Poles, the specific gravity of the vapour at the level of the sea, would always exceed its specific gravity at any height above. Hence, in an atmosphere of vapour, there would be no tendency to vertical currents.

Having thus stated the leading properties of an atmosphere of air, and of an atmosphere of vapour, separately, we come to the proper subject of our inquiry; viz., the condition of an atmosphere resulting from a mixture of air and vapour—of such an atmosphere, indeed, as that in which we actually live.

The reader will have no difficulty in understanding the nature of a mixed atmosphere; provided he has clearly apprehended what has been above stated, regarding the simple atmospheres which are its components; and will advert to two other circumstances, that are now to be noticed. These two circumstances are intimately connected with the principles previously stated, and with each other; and an exposition of them is absolutely necessary for obtaining a true knowledge of the relations between an atmosphere of vapour, and an atmosphere of air. These circumstances have not been mentioned sooner; the consideration of them having been intentionally delayed, in order that their influence might be seen, where their application is more immediately requisite.

When vapour and air are mixed together, the resulting volume of the mixture depends on the amount of the elastic forces of the vapour and of the air; not on any relation between their volumes. Thus when a cubic foot of air at the temperature of 32°, and exerting an elastic force equal to 30 inches of mercury, is mixed with a cubic foot of vapour, having the same temperature, and exerting an elastic force equal to only 1-5th of an inch of mercury; the volume of the mixture resulting, is not two cubic feet, but only 1·0066 foot. Hence, as the addition of vapour

to air adds comparatively little to the bulk of the air, and consequently diminishes only in a trifling degree its specific gravity; the great aërial currents formerly described as pervading the atmosphere, are scarcely affected by the vapour they contain.

When two portions of vapour, having different temperatures, are mingled together; or when a portion of vapour is brought into a state of mixture or contact, with a portion of water, or with any other body colder than the vapour; the resulting mean temperature, whatever that mean may be, is, in both cases, the temperature which regulates the elastic force of the mixture. Now, since the elastic force of vapour increases most rapidly from the temperature of 32° to 212°, the increase being in a geometrical progression; while the increase of the temperature is in an arithmetical progression; it follows, that when two portions of vapour, of equal bulk, but of different temperatures, are mixed together; or when a portion of vapour is brought into contact with any solid colder body; the resulting mean temperature is always below the temperature requisite to preserve the water in a state of vapour. Hence, such mixture or contact is always followed by a portion of the vapour being condensed into water. In a future part of this section, it will be necessary to illustrate further this important fact; but a familiar instance may be noticed here. Let us suppose that a pound of water at the temperature of 212°, which being in a state of steam would occupy a space of about 27 cubic feet, were suddenly brought into mixture with a pound of water at a temperature of 32°; the effect would be an instantaneous condensation of the greater part of the steam into water. For, the resulting mean temperature would obviously be far short of 212°, below which temperature, the elastic force of vapour most rapidly diminishes. On this property of vapour, depends the working of the common steam-engine.

The reader is thus at length prepared to enter on the complicated subject of a mixed atmosphere of vapour and of air.

We have shown that the rate of decrease of the temperature of an atmosphere of vapour, in ascending from the earth's surface, would be very much slower than the

rate of decrease of the temperature of the atmosphere of air. Now, at all temperatures, the existence of atmospherie air is permanent; while the very existence of vapour is dependent on temperature: it follows, therefore, that in a mixed atmosphere of vapour and of air, the quantity of vapour contained in the mixture, is regulated solely by the temperature of the air: that is to say, the quantity of vapour present in an aërial atmosphere, can never exceed, though it may be less than, the quantity which is proper to the temperature of the air. If the quantity of vapour in such a mixed atmosphere, be precisely the quantity which is proper to the temperature of the air; such an atmosphere is said to be saturated with vapour.

But, neither at the earth's surface, nor at any height above the surface, can the degree of saturation of a mixed atmosphere of air and vapour, be quite equal to the saturation which is proper to the temperature of the air; and the difference between these two degrees of saturation augments from above, downward. The cause of this difference may be thus explained. The rate of increase of the temperature of air from above, downward, being in arithmetical progression; and the air being, in a mixed atmosphere, that ingredient which controls the whole mixture: the rate of increase of the tension of the vapour, instead of following the geometrical rate which belongs to vapour increasing in temperature; is obliged to conform to the arithmetical rate of increase of the temperature of the air. The result of this controlment necessarily is, that the quantity of vapour present in a mixed atmosphere will, at any successive diminution of the height above the surface of the earth, become successively less and less than the quantity which would be required to saturate the air. An example will make this result evident.

At the Equator, as we have said, the temperature of the air, about 15,000 feet above the level of the sea, is nearly 32°. Now, for the sake of illustration, let us suppose the air at this height to be saturated with vapour. From Dr. Dalton's table of the tension, or elastic forces, of vapour at different temperatures, it appears that the tension of vapour at 32° is equal to the weight of ·200 inch of mercury; and that the difference between the ten-

sion of vapour at 32°, and the tension of vapour at 33°, the value, namely, of the first term or unit, in our assumed arithmetical series, is ·007 inch of mercury. Now, the difference between 32°, and 80°, the mean temperature at the level of the sea under the Equator, is 48°. Supposing, therefore, each of these 48 degrees to increase in an arithmetical progression, ·007 for each degree; the tension for the whole 48 degrees will amount to ·336; which tension added to ·200, the tension at 32°, gives ·536 inch, as the tension corresponding to vapour at 80°, the temperature of the earth's surface under the Equator. But, by Dr. Dalton's same table of tensions, we find that ·536 does not represent the proper tension of vapour of 80°, but of vapour at about 61° only. According to this estimate it follows, that at the Equator, while the temperature of the air over the earth's surface is 80°, the point of saturation of the air with vapour is 19° below that temperature. Hence, at the Equator, the air immediately incumbent on the earth's surface must be comparatively dry. Moreover the cause which has been thus shown to produce the dryness of the Equatorial air, at the earth's surface, must all over the globe exert different degrees of the same influence. The air, everywhere incumbent on the earth's surface, must, therefore, always be under the point of saturation;—the relative degree of dryness being highest under the Equator, and gradually diminishing as we recede north or south toward the Poles.*

In such a mixed atmosphere, as we have supposed, and as in reality surrounds our globe, if its equilibrium be undisturbed, and if it be conceived to be at rest; the admixed vapour will have nearly the same tendencies to motion, which would exist in an atmosphere of pure vapour, formerly described. But, from the more equal distribution

* The mathematical reader will observe, that the quantities given in the text are not rigidly accurate, but are intended only for familiar illustration of the principles regulating moisture. The truth is, as has been noticed in the text, in no part of a vertical column of a mixed atmosphere, in a condition of equilibrium and at rest, can the air be in a state of saturation. It has been found, that the degree of saturation often continues nearly uniform up to a certain point, and then suddenly decreases.

of the vapour, when mingled with the air; the contrasts between the specific gravities of different portions of vapour, in different parts of the atmosphere, will be much less striking, than if the atmosphere consisted of vapour alone. Consequently, the rates of motion depending on such differences of specific gravity, will be less remarkable in a mixed atmosphere, even though saturated with vapour, than they would be in a purely aqueous atmosphere; while in an unsaturated atmosphere, the motions of the vapour must be still more liable to be influenced by the motions of the air, than they would be in an atmosphere of air, at its utmost point of saturation.

Before we close this part of our subject, let us reflect for a moment, on the consequences of the state of comparative dryness of the lower atmosphere next the surface of the earth. Over the greater portion of the earth, the air which, during the day at least, is warmed by contact with the earth's surface, and thus becomes lighter, has, as we have said, a constant tendency to rise into the higher atmosphere. Now, if this air were saturated with vapour; of course, whenever the air by rising became mixed with colder air, its vapour would be more or less condensed, and a cloud would be formed. Hence, if we lived in such an atmosphere, we should be always enveloped in a mist, through which the sun would not be visible. But, by the benevolent arrangement we enjoy, this consequence is so entirely prevented, that, unless under peculiar circumstances, and always for beneficial purposes, the air at the earth's surface is hardly ever saturated with moisture. The air which has been warmed by contact with the earth, can therefore, rise from the surface, without any condensation of its moisture within the limits of its point of saturation. Thus, at the Equator, before the air reaches the temperature of 61°, the presumed point of its saturation, it must ascend to the height of 6000 or 7000 feet. At this height, its vapour will be condensed, and a cloud will be formed; which may either be precipitated on the spot from which its constituent vapour had risen; or may be transported by the currents of the atmosphere, similarly to refresh a distant country; or may be again dissolved in the air: while under all these contingencies, the whole of the lower portion of the atmo-

sphere is exempt from mist, and continues perfectly transparent. These operations are unceasing: moreover, the very clouds, by giving out their latent heat, and shielding the earth's surface from the direct influence of the sun, produce a still further effect; and have a constant tendency to modify their own formation and existence.

The general result of all the complicated and beautiful machinery connected with the properties of vapour, is, as before observed, that over the whole earth, water is constantly ascending into the atmosphere, where it is again condensed in the form of rain, &c. We shall therefore examine a little more in detail, the relations of the two great processes of evaporation and condensation, by which these important arrangements are accomplished.

Thirdly. *Of the general relations of evaporation and condensation as they exist in our atmosphere: and of the circumstances by which these relations are influenced.*—We have already described the general phenomena of evaporation and condensation, and have stated the laws on which these phenomena depend. It will, consequently, in this place, be sufficient to remind the reader, that the degree, and the rate, of evaporation, though they increase with the temperature, are regulated chiefly by the existing degree of saturation of the air. That is, under all temperatures, evaporation decreases, as the air which receives the vapour, approaches its point of saturation.

From this statement it follows, that in an atmosphere perfectly saturated with moisture, and in a state of thermal and dynamical equilibrium, there can be neither evaporation nor condensation. The processes of evaporation and condensation, therefore, always indicate a disturbance of the thermal equilibrium in some part of the atmosphere: condensation denoting a depression of the temperature below the mean, or point of thermal equilibrium: evaporation, on the contrary, denoting that the temperature in some part of the atmosphere has been raised above the mean; or at least that the temperature having been depressed below the mean, is again undergoing an elevation to the mean point. Evaporation and condensation may be thus considered as mutually dependent; so that one process cannot take place without the other. For this reason, in the great expanse of

nature, these two processes oscillate or fluctuate about the point of equilibrium, within certain limits which are never passed; and which limits, though subject to countless anomalies, in general, decrease from the Equator toward the Poles.

With respect to the temperature which constitutes the point of equilibrium; in an atmosphere of vapour, that point would, of course, be the maximum point of saturation. But in a mixed atmosphere of vapour and air, like the atmosphere of our globe, the point of equilibrium cannot be the point of utmost saturation: it must be that inferior point of saturation formerly noticed, as being determined by the temperature of the predominant air. Thus, at the Equator, where the mean temperature at the level of the sea is about 80°, the mean point of saturation will, according to our former estimate, be 61°; while in London, where the mean annual temperature is about 49½°, the mean point of saturation, (or the dew point, as it is termed,) has been fixed by Mr. Daniell at 44½°. In temperate climates, the mean point of saturation, at any particular place, varies with the seasons from day to day, being higher in summer than in winter. During any shorter period, as during a day and night, the mean point of saturation, as might be expected, generally bears a relation to the lowest temperature the air has reached during that short period; since the Hygrometer* shows that the degree of saturation, at any hour, is seldom below the point of saturation corresponding to the lowest temperature of the twenty-four hours, at which temperature, saturation continues nearly uniform; so that the point of saturation during the warmer parts of the day generally varies only a few degrees. The elevation and depression of the dew point in temperate climates is thus another, and unceasing cause of change; and produces a variety in evaporation and condensation so great, as to baffle any attempt at accurate inquiry.

From what has been said, it will appear that in a mixed

* The Hygrometer is an instrument for measuring the degree of moisture of the atmosphere. Mr. Daniell's Hygrometer is here alluded to, which is the only one acting on scientific principles. Daniell's hygrometer shows the degree of temperature at which water is deposited from the atmosphere, and consequently its state of saturation.

atmosphere, the rate of evaporation and of condensation, other things being equal, will depend, not on the difference of the temperature of the air from the maximum point of saturation, but on the difference of the temperature of the air from the temperature of the mean dew point; that is to say, the rate of evaporation and of condensation will increase or diminish in the same degree as the temperature of the air rises above, or falls below, the temperature of the mean dew point.

Of the nature and causes of the motions of the vapour through the air of the atmosphere.—Water is dispersed through the atmosphere in two ways: viz. by the motions of vapour properly so called; and by the motions of visible vapour or clouds.

With respect to the motions of vapour properly so called, it may be remarked that vapour is circulated through the atmosphere partly by convection, but chiefly by means of that tendency before described which water possesses at all temperatures to assume the form of vapour, and to diffuse itself through the air. In a mixed atmosphere of vapour and air, the motions of the vapour on the large scale of the operations of nature, are considerably influenced no doubt by the motions of the air. For example, large masses of air more or less saturated with vapour in proportion to their respective temperatures, and having either vertical or lateral motion, must carry with them the vapour they contain, whether there be much or little vapour so contained. On the other hand, motions of the air on a smaller scale, as we shall presently see, may be even caused—may certainly be accelerated or retarded according as the diffusive motion of the vapour next to be considered, may agree with or may be opposed to these motions of the air.

In an atmosphere of vapour, when the temperature and consequently the elasticity of any portion is reduced, the surrounding vapour by virtue of its greater elastic force, continues to advance toward the cooler locality, and to be there condensed until the thermal equilibrium is restored. The motion thus arising depends on the dynamical properties of vapour; and in an atmosphere of vapour, this restoration of the dynamical equilibrium, which depends on the thermal equilibrium, would take place with so great rapidity

as to be almost instantaneous. But in a mixed atmosphere the case is different; in such an atmosphere, the presence of the heavier and more abundant air exerts a remarkable control over the rapid motion of the lighter and less abundant vapour. Hence, instead of a rush of vapour and a momentary deluge, the diffusive motions of the vapour take place slowly; and sudden evaporation and condensation with their consequences are effectually prevented.

These tendencies to diffuse motion in vapour of different temperatures, have no doubt, great influence on the contiguous surfaces of large masses of air differently saturated; and in particular, are liable to affect smaller masses of air differently saturated when these smaller masses are in the immediate neighbourhood of each other. Thus, as we have already noticed, the disturbance of the equilibrium of the vapour, may be to such an extent in some portion of the mixed atmosphere, that the surrounding vapour, urged to move by its tendency to restore the equilibrium, may occasionally be supposed to drag with it the air and the clouds, and thus to produce local currents. For instance, let us imagine a mass of warm and almost perfectly dry air to be brought into the neighbourhood of another mass of air of precisely the same temperature, but saturated with vapour. The two masses of air, from being of the same temperature, would as air, have no tendency to intermingle. But being portions of a mixed atmosphere of vapour and air, the dryer air would be, as it were, a vacuum, towards which the vapour from the moist air would have a tendency to flow, till both masses of air became equally moist. In such a case, the motion of the vapour might be supposed to cause more or less of motion in the air, while a momentary cloud would probably be formed; which cloud would be dissipated when the equilibrium was restored. In this way, it is likely that some of tho minor motions of the atmosphere are produced.

The motions of visible vapour of clouds, aro principally caused by currents in the atmosphere or winds, and by electricity. Although the proper motions of vapour aro liable, as we have said, to be considerably influenced by atmospheric currents; yet vapour, properly so called, is much less liable to be so affected, than visiblo vapour; for

when once the vapour in the atmosphere has been separated, and has assumed the form of visible vapour, its own proper powers of motion cease; and the vapour becomes, as a cloud, entirely subject to the power of convection. Visible vapours, therefore, of all kinds, from their liability to be wafted by every breeze, are in a constant state of motion; and are thus frequently carried where vapour, in virtue of its mere diffusive property, would never reach.

Another undoubted cause of the motions of visible vapour or clouds, is Electricity. Electricity is not known to exert any influence on the motions of water through the atmosphere, so long as the water remains simply vapour; but the moment the water is precipitated and assumes the form of visible vapour, that is, becomes a cloud, the water in this form becomes also subject to electrical attractions and repulsions, by which the motions of clouds are much liable to be influenced; as will be more particularly explained hereafter.

Of the accidental circumstances affecting evaporation.— The accidental circumstances which principally operate to affect the rate of evaporation, are the greater or less extent of the evaporating surface, and the velocity of saturation, together with the degree in which the current of air over the evaporating surface has itself been previously saturated with moisture. But besides these causes of change, there are other circumstances which probably have great influence on evaporation; some of which are to us of the utmost interest, from their being brought more immediately in contact as it were with our existence. The chief of these additional circumstances affecting evaporation which we shall notice are;—circumstances incidental to the water which undergoes evaporation; and circumstances incidental to the air into which the water is evaporated.

The most important peculiarity of aqueous evaporation, is, that the rate of evaporation, so far as we know, is not at all affected by the circumstance of the water being frozen. Thus Howard mentions an instance in the month of January in a certain year, when the vapour from a circular area of snow five inches in diameter, amounted to 150 grains between sunset and sunrise; and before the next evening, 50 grains more were added to the amount, the gauge having

been exposed to a smart breeze on the housetop. Under like circumstances, an acre of snow would, in the course of twenty-four hours, evaporate the enormous quantity of 64,000,000 grains of moisture! Even by evaporation during the night only, a thousand gallons of water would, in that short time, be raised from an acre of snow. It may thus be easily understood, how a moderate fall of snow may entirely vanish during a succeeding northerly gale, without the slightest perceptible liquefaction on the surface.* We have given this statement to satisfy the general reader of the fact, that evaporation is constantly going on from snow and ice; indeed there is every reason to believe, as before stated, that the quantity of vapour thus formed from snow and ice is precisely equal to what would be evaporated from water itself, provided water could exist as a fluid below the temperature at which it is congealed.

The other circumstances incidental to water undergoing evaporation arise chiefly from its purity or impurity. The presence of foreign bodies in water, as of saline matters, for instance, is well known to raise considerably the boiling point of that liquid; in other words, foreign bodies obviate the tendency of water to become vapour, and thus diminish its evaporating and its saturating powers. Hence the air over the sea, though of course, much nearer in general to the point of saturation appropriate to the latitude and temperature than air over the land, is comparatively seldom in a state of perfect saturation; and sea-water, so far from being capable of saturating the air with moisture up to the dew point, has even the power of abstracting a portion of the moisture from an atmosphere so saturated, and thus, to a certain extent, of drying the air.

Evaporation on land is precisely similar to evaporation from sea-water; since the various rocks and soils may be considered as so many saline matters, diminishing in their several degrees, the tendency to become vapour possessed by the water united with them. Under like circumstances, therefore, some rocks and soils are dry, while others are moist; so that, in proportion to the evaporating powers of the rocks and soil of a country, will that country be liable to all the effects of dryness or of dampness of soil. Plants

* Article "Meteorology," in the Encyclopædia Metropolitana.

also seem to differ much in their capacity for retaining water. The dryness of a country will, consequently, be considerably influenced by the nature of its vegetation; and the predominance of certain plants or trees in a district may thus increase the dampness of its soil.

Regarding the effect which foreign matters in the atmosphere produce on evaporation from the subjacent land or water, we are unable to speak with as much confidence as of the controlling power of the foreign matters existing in the water itself. There is however, reason to believe that certain constituent elements of the atmosphere are occasionally associated, so as to form compounds; and that these compounds, acting as foreign bodies, materially influence evaporation. See Appendix.

Of the accidental circumstances which influence condensation.—The condensation of vapour from the atmosphere, as we have already stated, differs in some degree, according to the origin of that diminished temperature by which the condensation is produced. We shall therefore commence with those phenomena of the precipitation of moisture from the atmosphere, which depend on the radiation of heat from the earth's surface into space. The most remarkable of these phenomena are Dew, Hoar Frost, and certain forms of Mist.

Of Dew.—The phenomena of dew were first satisfactorily explained by the late Dr. Wells; who showed by the most decisive experiments, that apparently, all these phenomena were owing to the effects of the radiation of heat from the earth's surface, during the absence of the sun. The reader is referred to Dr. Wells' "Essay on Dew," for details. It is sufficient for our present purpose to observe, that when the direct influence of the sun is removed in the evening, and the surface of the earth thus no longer continues to acquire heat; at that instant, from the ceaseless activity to maintain a state of thermal equilibrium, the surface of the earth, being the warmer body, radiates a portion of its superfluous temperature into the surrounding space; and thus the air immediately in contact with the surface, becomes cooled below the point of saturation, and gives off a portion of its water in the form of dew.

We formerly stated, that the radiating powers of bodies

differ exceedingly according to their composition, the nature of their surface, their colour, &c. These differences, of course, produce corresponding effects on the deposition of dew; and, as has been beautifully demonstrated by Dr. Wells, explain its greater or less deposition under certain circumstances, or its entire absence under others. Thus, what formerly appeared so extraordinary, viz. why in the self-same state of the atmosphere, &c. one portion of the earth's surface, or one portion of herbage, should be covered with dew, while another in the immediate neighbourhood should remain dry, is no longer a mystery; but is perfectly explicable on the supposition of their different radiating powers.

The deposition of dew is always most abundant during calm and cloudless nights, and in situations freely exposed to the atmosphere. Whatever interferes in any way with the process of radiation, as might be expected, has a great effect on the deposition of dew. The radiation of heat therefore, and consequently the deposition of dew, are obviated not only by the slightest covering or shelter, as by thin matting, or even muslin, by the neighbourhood of buildings and innumerable other impediments near the ground, but matters interposed at a great distance from the earth's surface have precisely the same effect. Thus clouds effectually prevent the radiation of heat from the earth, so that cloudy nights are always warmer than those which are clear; and in consequence, there is usually on cloudy nights little or no deposition of dew.*

From dew there is an insensible transition to Hoar Frost; hoar frost being in fact only frozen dew, and indicative of greater cold. We see, therefore, that frosty nights, like simply dewy nights, are generally still and clear.

The influence of radiation in producing cold at the earth's surface, would scarcely be believed by inattentive observers. Often on a calm night, the temperature of a grass plot is 10° or 15° colder than that of the air a few feet above it. Hence, as Mr. Daniell has remarked, vegetables in our climate are during ten months of the year, liable to be exposed at night to a freezing temperature;

* See the Memoir by Melloni, in Taylor's Scientific Memoirs, vol. v.—G.

and even in July and August to a temperature only two or three degrees warmer. Yet, notwithstanding these vicissitudes, in the words of the same author, "To vegetables growing in climates for which they are originally designed by nature, there can be no doubt that the action of radiation is particularly beneficial, from the deposition of moisture which it determines upon the foliage; and it is only to tender plants, artificially trained to resist the rigours of an unnatural situation, that this extra degree of cold proves injurious."* It may be added, that trees of lofty growth frequently escape being injured by frost, when plants nearer the ground are quite destroyed.

Of Mists and Fogs.—Mists are not necessarily connected with the deposition of dew; because during the deposition of dew, the atmosphere often continues transparent, even to the earth's surface. At other times however, and for reasons which in the present state of our meteorological knowledge cannot be satisfactorily assigned, the deposition of dew is accompanied by a visible vapour or mist, more or less dense, and extending from the surface of the earth to a greater or less height in the atmosphere. When mists from other causes are general, and extend to considerable heights above the earth's surface, they acquire the name of fogs. The optical properties and the buoyancy in the atmosphere of mists and fogs, would seem to indicate that they are not formed of solid particles, but of minute hollow vesicles having the quality of mutual repulsion; the tendency to repel each other preventing the coherence of the vesicles into drops, at least under ordinary circumstances. These vesicles have been occasionally observed of considerable magnitude. Thus Saussure, in one of his Alpine journeys, saw vesicles float slowly before him having greater diameters than peas, and whose coating seemed inconceivably thin. It is proper to mention however, that there is diversity of opinion respecting the actual constitution of visible vapour.

That the cause of the formation of mists and of fogs is to a certain extent, similar to the cause of the formation of dew, appears by their prevalence over rivers and large masses of water, especially during the autumnal months.

* Meteorological Essays and Observations, p. 511, second edition.

The radiation of heat from the ground and from the water is at that season very different, owing to the difference of their temperatures being then greatest. In autumn the temperature of the water is both by day and by night nearly uniform at 40°, its point of maximum density; while the temperature of the ground is, during the day, much higher than 40°, and during the night often much under that temperature. The water in most cases occupying the lowest situations, whenever from the inequalities of the surface of the ground, or from any other cause, the colder air produced by radiation over the ground is made to mix itself with the warmer air over the water, the moisture in the warmer air is condensed so as to become mist. Hence the cause of the formation of mist differs slightly from the cause of the formation of dew; inasmuch as there is occasionally (not always) an intermixture of air of different temperatures when mist is formed. We can thus easily explain the fogs and mists so frequently seen over rivers and in valleys, or in other situations where there is a collection of water. The occurrence of such mists is usually on clear and cold nights,—oftenest in autumn, and seldom or never in cloudy weather; the state of the atmosphere having exactly the same influence on these mists as on the deposition of dew. There cannot be a doubt that these mists, like clouds, produce a great effect in impeding radiation and mitigating the intensity of cold. Mists are therefore of much importance in the economy of nature. Plants growing in low grounds are by them shielded from the destroying influence of the sudden cold which would almost unavoidably be produced, not only by the free radiation of heat in such situations, but by the descent of cold air from the surrounding high grounds.

The fogs which hang over great towns admit of an explanation similar to that of other aqueous fogs. The air of the town being warmer than the air of the surrounding country, and being at the same time charged with moisture nearly to the point of saturation, is in cold weather suddenly cooled, either by the radiation of its own heat, or by the admixture of the neighbouring cold air, while the superfluous moisture is condensed as a fog.

The fogs of high latitudes, more especially the fogs of

the Polar seas, are in the same manner owing to the radiation of heat. The cooling of the air over the immense masses of floating ice, gives rise to an unequal distribution of temperature, and thus at certain seasons, to uninterrupted fogs. It is probable that in all these instances, the fogs beneficially alleviate the severity of cold, by checking great and sudden alternations of temperature which would otherwise much interfere with the operations of organic life.

Fogs have been sometimes observed of a strong odour, apparently the result of an admixture of foreign bodies. In a subsequent paragraph these fogs will be more fully considered.

Of Clouds.—From mist and fogs the transition to clouds is easy and natural; as clouds, in reality, are nothing more or less than masses of visible vapour, precisely similar to the vapour composing fogs, but produced at a distance above the earth's surface. Clouds differ principally from mists and fogs in their mode of formation. Thus mists like dew, as we have seen, are the result of the cooling of the lower strata of the atmosphere by radiation. Fogs are so far the result of radiation, that they usually arise from the influence which air cooled by radiation exerts on warmer air. While clouds probably depend altogether on convection, and result from the intermixture of strata of air of different temperatures and in different states of saturation in the higher regions of the atmosphere.

Such is the general opinion of the formation of clouds; but it must be confessed that there are considerable difficulties about the subject, and that the mere assumption of strata of different temperatures, more or less saturated with vapour, and having the motions supposed to depend on such different temperatures and degrees of saturation, seems quite inadequate to account for all the phenomena connected with the formation and appearance of clouds.

From the principles formerly stated when we described the phenomena and properties of a mixed atmosphere of air and vapour, it appears that clouds in general must be formed at that elevation in the atmosphere, in which the mean temperature of the air becomes equal to or falls below the point of saturation of such air. This elevation,

which may be said to constitute the region of clouds, must of course be highest under the Equator—an inference supported by fact; for it has been observed that within the tropics, the clouds are most frequently higher than in the temperate zones; and in the temperate zones, the clouds appear to be higher in summer than they are in winter. In the temperate zones, Gay Lussac thinks that clouds in general, are upheld at an average distance from the earth's surface of between 1500 and 2000 yards. Occasionally, however, clouds have a much greater altitude; and the Cirrus, a form of cloud to be presently described, has been seen far above the greatest elevation hitherto attained by man.

In some parts of the world, clouds are rarely seen; while in other parts, the sky is seldom cloudless. Such extremes are usually confined to extreme climates, or depend on local causes. In the temperate zones, from the irregularity of the atmospheric currents, and from the other innumerable circumstances calculated to disturb the equilibrium of the atmosphere, the general character of clouds varies much, even under the same parallel of latitude. Hence all the infinite variety of sunshine, and of shower, which more especially distinguish the temperate zones, and our own variable sky in particular; where they exert such constant and commanding influence on our comfort and well-being, as to become almost interwoven with our very existence.

Though clouds are of endless diversity of figure and appearance, they have been classed by Howard under three primary forms, and four modifications. The three primary forms are:

The Cirrus, composed of fibrous-like stripes, parallel, flexuous, or diverging, and extensible in all directions.

The Cumulus, heaped together, in convex, or in conical masses, and increasing upward from a horizontal base.

The Stratus, spreading horizontally in a continuous layer, and increasing from below.

The first of these forms, the cirrus, is confined chiefly to the higher regions of the atmosphere. The second form, the cumulus, occupies a lower but still an elevated station; while the third form, the stratus, usually rests on the sur-

face of the earth, constituting the mists already described in this chapter.

Of the four modified forms of clouds, two are intermediate, and two are composite.

The first of the intermediate forms is the Cirro-Cumulus, consisting of small roundish and well-defined masses, in close horizontal arrangement.

The masses that compose the second intermediate form of clouds, the Cirro-Stratus, are likewise small and rounded, but are attenuated towards a part, or towards the whole of their circumference. They are sometimes separate: when in groups, their arrangement is either horizontal, or slightly inclined, and the masses are either bent downwards or are undulated.

Of the two composite forms of clouds, the first is the Cumulo-Stratus, made up of the Cirro-Stratus blended with the Cumulus; the Cirro-Stratus being either intermingled with the larger masses of the Cumulus, or widely enlarging the cumulous base.

The second composite form, and the last of the four modifications of clouds, is the Cumulo-Cirro-Stratus or Nimbus, the rain-cloud; being that cloud, or system of clouds, from which rain is falling. The nimbus is a horizontal layer of aqueous vapour, over which clouds of the cirrous form are spread; while other clouds of the cumulous form, enter it laterally and from beneath.

A little attention will enable any one to discriminate these varieties of clouds; at least when their forms are well defined. Yet, it must be acknowledged that clouds often assume forms to which it is difficult to give a name.

With respect to the motion of clouds, it may be remarked that there is not perhaps a more frequent subject of optical delusion, nor anything regarding which we are more liable to be mistaken. Into such inquiry it would be quite inconsistent with the design of this treatise were we to enter minutely; but we offer the following brief illustration. Let us suppose a cloud moving from the distant horizon toward the place where we stand. Let us also suppose that the cloud during its motion, retains its size and figure unchanged, and that it proceeds along its course in a uniform horizontal line. A cloud so moving, when first

seen will appear to be in contact with the distant horizon; and will thus necessarily, from its remote position, appear to be much smaller than in reality it is. During its advance toward us, the cloud will seem to rise into the sky, and to become gradually larger, till it is completely overhead. Continuing its progress, it will then seem again to descend from the zenith, and to lessen in size as gradually as it had before increased: till at last it vanishes in the distance, opposite to where it commenced its movement. Thus the same cloud, without deviating from its motion in a straight line, and retaining throughout the same size and figure, will, by optical delusion, seem continually to vary in magnitude. The line of its motion also, instead of being straight, will appear to be a curve having its vertex directly above us, and its extremes boundless in opposite points of the horizon. We have given the most simple case that can be supposed. But clouds, as they exist in nature, are unceasingly varying in shape, in magnitude, in course, and in velocity; so that to form a just estimate of their figure and direction, or to unravel their motions, becomes absolutely impossible.

After what has been stated, it will be superfluous to dwell on the uses of clouds in the economy of nature; we shall therefore briefly remind the reader of a few only of the most obvious benefits derived from clouds. The first of these benefits claiming our attention, is that on the large scale at least, clouds constitute a sort of intermediate state of existence between vapour and water, by which sudden depositions of water and the consequences are entirely prevented. If all the water separated from the atmosphere fell at once to the earth in the state of water, we should be constantly liable to deluges and other inconveniences, the whole of which are obviated by the present beautiful arrangement. Again, clouds are one great means by which water is transported from seas and oceans to be deposited far inland, where water otherwise would never reach. Clouds also greatly mitigate the extremes of temperature. By day, they shield vegetation from the scorching influence of the solar heat, and produce all the agreeable vicissitudes of shade and sunshine: by night, the earth wrapt in its mantle of clouds is enabled to retain that heat which would otherwise radiate into

space, and is thus protected from the opposite influence of the nocturnal cold. These benefits arising from clouds are most felt in countries without the Tropics, which are most liable to great changes of temperature. Indeed, clouds constitute one great means by which in temperate climates, the extremes of heat and cold are regulated. Lastly, whether we contemplate them with respect to their form, their colour, their numerous modifications, or, more than all, their incessant state of change, clouds prove a source of never-failing interest, and may be classed among the most beautiful objects in nature.

Having finished the consideration of the various states of visible vapour, we are now to examine the phenomena of the precipitation of water from the atmosphere in the form of Snow, Sleet, Rain, and Hail. We shall first speak

Of Snow.—We commence with snow, because it offers the most simple case of the precipitation of water from the atmosphere, snow being nothing more than the frozen visible vapour composing clouds. Hence a flake of snow, examined with a high magnifier, exhibits a beautiful display of minute crystals, often possessing the greatest variety of figure.

When the temperature of the atmosphere down to the earth's surface is constantly below the freezing point, it is obvious that any moisture separated from the atmosphere must assume the solid form. If the quantity separated be small, the frozen particles of water remaining detached, float in the atmosphere in the state of crystallized spicula, and thus give origin to what is called the frost-smoke, a phenomenon not unfrequently witnessed in polar latitudes. Even in temperate climates, the same thing has been supposed occasionally to take place in the higher regions of the atmosphere, and thus to produce certain optical phenomena to which we shall hereafter refer.

The above are comparatively rare phenomena. Most generally, the quantity of water separated is so large, that the crystallized particles are agglutinated together into masses or flakes, and thus fall down in the form of snow. When the quantity deposited is very great, as is often the case, there can be no doubt that the causes operating to produce large deposition are precisely similar to the causes

which produce rain in warmer climates, and which will be considered in a subsequent paragraph.

Such in few words is the mode in which snow is formed; and being thus formed the reason is at once apparent why during the winter in temperate climates, and throughout the whole year in the Polar climates, most of the water that falls to the earth assumes the condition of snow.

We formerly mentioned how much we owe to the whiteness of snow, and we may now add that we owe still more to its low conducting properties and to its lightness. Thus, by its low conducting properties, snow shields vegetation from the rigorous cold of the higher latitudes, where every thing herbaceous would be destroyed during the winter, were it not for the protecting influence of snow. Again, if the water which now descends to the earth as snow, were to be precipitated in the form of solid masses of ice, vegetation would be destroyed, and the whole of the colder parts of the world would be uninhabitable!

It has been remarked, in temperate climates more especially, that the air is usually warmer while snow is falling, than before or after. This increase of temperature probably arises from the extrication of heat in the sensible form, during the transition of the vapour from a fluid to a solid state. Snow-water has also been said to contain much oxygen, and thus to be particularly favourable to vegetation.

Sleet is half melted snow, and constitutes the intermediate condition of water between the condition of snow and that of rain, to be next considered.

Of Rain.—When the temperature of the air is above 32°, the freezing point of water, the water separated from the air falls to the earth in the state of rain. Such is a general expression of the fact; but after all the attention that has been bestowed on the phenomena of rain, many difficulties attend the investigation which have not yet been surmounted.

It cannot be doubted that rain is in some way connected with change of temperature; the perplexity attending the subject arises, partly from the impossibility in many instances of accounting for the supposed change of temperature, but much more from the difficulty of understanding

how this change of temperature operates. According to the usual opinion, the precipitation of water from the atmosphere is the effect of the mingling together of currents of warm and of cold air, which are supposed to act on each other in the following manner:

From the law of the tension of vapour already described, it follows that when two currents of air having different temperatures but both alike saturated with vapour, are mixed together, though the resulting temperature of the mixture will be the mean of the two, the resulting tension of the vapour will not be likewise the mean. The resulting tension of the vapour will always exceed the tension belonging to the resulting mean temperature; consequently there will be an excess of vapour which will be precipitated in the form of water. Thus let us suppose two currents of air both saturated with vapour, the one having a temperature of 40°, and the other a temperature of 60°; and that these two currents of air are mingled together;

		Inch of Mercury.
The tension or elastic force of vapour at 40° is equal to	-	·263
" " of vapour at 60° is equal to	-	·524
		·787
Mean Tension	- -	·393

Whence it appears, that the mean temperature of the two volumes of air is 50°, and the mean of the elasticities of their vapour ·393 inch. But the actual tension or elastic force of vapour at 50°, is not ·393 inch, but only ·375 inch: after the intermixture therefore, of the two currents, a quantity of vapour will remain, proportionate to the tension of ·018 inch; and as this superfluity of vapour cannot be held in solution by air of the mean temperature of 50°, it will be separated in the form of clouds or of rain according to circumstances.

Such in few words, are the opinions respecting rain first advanced by Dr. Hutton; and notwithstanding some difficulties about these opinions, there can be little doubt of their general accuracy. The subject of condensation may perhaps be further elucidated by the principles regulating a mixed atmosphere of vapour and air, which were formerly explained:

When two currents of atmospheric air of different temperatures, and each charged with vapour up to the point of saturation, are brought into contact, they begin to intermingle by virtue of the diffusive tendencies of the air and vapour, and the immediate result will be the formation of visible vapour, that is to say of a cloud. If the currents are continuous and uniform, the clouds soon spread in all directions, so as to occupy the whole horizon ; while the additional moisture incessantly brought by the warmer current keeps up a constant supply for condensation, and produces a great and continued deposition of moisture in the form of rain. By degrees, the currents completely intermingle and acquire a uniform temperature, condensation then ceases, the clouds are redissolved, and the whole face of nature after being cooled and refreshed by the necessary rain, is again enlivened by sunshine, thus rendered still more agreeable by its contrast with the previous gloom.

In this manner the principles formerly detailed may be applied to the explanation of the phenomena of rain; and as far as the explanation goes, it is perhaps quite satisfactory. It must however, be allowed as we have before stated, that the utmost information we can at present bring to bear on the subject of the general condensation of moisture from the atmosphere, and of rain in particular, leaves it involved in considerable obscurity.

The following additional particulars regarding the effects of different localities, and of different circumstances in the same locality, which appear to influence the fall of rain, may interest the general reader.

It has been remarked, that in the greater number of instances, more rain falls in the neighbourhood of the sea, than at sea ; a fact easily understood from the principles which have been stated. Among mountains also more rain falls than on plains; the excess is indeed striking. Thus in our own country, at Kendal and Keswick, both inclosed by mountains, the annual fall of rain amounts to $67\frac{1}{2}$ and 54 inches respectively ; while in many inland places the quantity of rain that falls in the course of a year hardly exceeds 25 inches. So at Paris, the annual fall of rain is only about 20 inches, but at Geneva, $42\frac{1}{2}$ inches ; and on the Great St. Bernard, the highest meteorological station

in Europe, upwards of 63 inches of rain fall during the twelve months.

Although more rain falls in mountainous districts than on plains, it has been completely established that more rain falls at the foot of a mountain than on its top. In general too, a larger proportion of rain is separated from the air near the earth's surface, than at any height above it; a discrepancy which, though it explains the fact just mentioned, is itself difficult to be explained in the present state of our knowledge.

In most Tropical countries, rain falls only at particular seasons of the year, there being scarcely any rain during the other seasons. Thus at Bombay, the rainy months are June, July, August, September, and October, while the other months are almost without rain; but on the opposite side of India, along the Coromandel coast, the time of the occurrence of the rainy season is reversed: facts strongly illustrative of the effect of the intervention of the high table land that separates the two coasts; and which probably by influencing the atmospheric currents, gives rise to this singular alternation of weather.

In temperate climates, though the total quantity of rain that falls be much less than within the Tropics, there is no protracted dry season, and the rainy days in the year are more numerous the nearer we go to the Poles. Still in general, more rain seems to fall in the temperate climates of the northern hemisphere during the last six, than during the first six months in the year.

Among the circumstances which influence the quantity of rain in the same locality, the most remarkable are diminution of temperature and the unusual prevalence of certain winds.

With respect to diminution of temperature, it has been observed that almost all wet seasons, or at least wet summers in temperate climates are unusually cold. Now from the principles formerly advanced it will be easily understood how a depression of the temperature below the general standard in any locality, may give rise to a greater precipitation of moisture in that locality. The locality which has become colder than those around it, acts as a refrigeratory, and not only condenses and thus deprives

of their elastic force all the vapours which are in contact with it, but the neighbouring vapours rush toward the colder locality as toward a vacuum, either in the form of visible vapour or clouds, in which case they are carried by the winds, or as invisible vapour in which form their movement may be determined by diffusion.

The effect of the unusual prevalence of certain winds in producing an increase of rain, or the reverse, is well known and is quite intelligible on the principles we have explained. Thus in tropical climates, during the steady prevalence of the trade winds, the currents intermingle but little, the atmosphere is perfectly cloudless and no condensation takes place. But when these great currents following the course of the sun begin at certain seasons of the year to shift their direction, their uniform course suffers derangement, they become intermixed, and condensations of moisture commensurate with the high temperature are produced to an extent quite unknown in temperate climates. These condensations form the violent periodical rains of hot climates. So also in temperate climates, as for instance in our own country, winds coming from the south and from the west are from a warmer climate and hold much vapour in solution, while winds from the opposite points are colder and are therefore relatively drier. Hence winds from the south and from the west are more frequently accompanied by rain, than winds from the north and from the east: though as we might expect, the precipitation of rain is most decided during the conflicts between these opposite currents which sometimes extend over a large tract of country. The long prevalence of certain winds may thus cause the seasons to be wet in one part of the world and dry in another, the water being as it were distilled off from the one, in order that it may be precipitated on the other. Yet the whole amount of the rain in the two countries may perhaps differ very little from the usual average, while the two countries have the benefit of variety in the general amount of their rain; which variety may be salutary at particular periods, and may even be necessary to their well being.

Before we end the examination of the phenomena of rain, it may be proper to advert to the generally admitted in-

fluence of the Moon on the weather, and especially on the fall of rain. This influence however, can hardly in the present state of our knowledge be brought to elucidate the phenomena of rain, so great are the disturbing effects of local and other peculiarities.

Of Hail.—The last form in which we have to consider the precipitation of water from the atmosphere, is hail. Hail may be regarded as consisting of drops of rain, more or less suddenly frozen by exposure to a temperature below 32°. If the degree of cold has been very sudden and intense, which is often the case, the icy nucleus from its being of a temperature far below the freezing point acquires magnitude as it descends, by condensing on its surface the vapour of the lower regions of the atmosphere. Hence, even under ordinary circumstances, hailstones often become of considerable size, are nearly always more or less rounded, and when broken are seen to be composed of concentric layers.

From what has been stated it will be readily inferred that hail is not a product of extreme climates; indeed hail may be considered peculiar to temperate climates, since it rarely ever occurs beyond the latitude of 60°. Hail is most frequent in spring and in summer, when it is often accompanied by thunder. It seldom hails in winter, and hail during the night is very uncommon. In tropical countries there is little hail in any place that is not more than 2000 feet above the level of the sea; in temperate climates on the contrary, mountain tops are almost free from hail. Certain countries especially some parts of France are very liable to hail storms, and such is at times the fury of these storms that they lay waste whole districts. There are on record many instances of these calamitous visitations, which are usually accompanied by whirlwinds and by the most appalling electrical phenomena. During storms of such degree of severity, hail-stones have sometimes fallen of enormous magnitude and often of an irregular shape, as if they were the fragments of a thick sheet of ice suddenly broken: a supposition which alone will explain the formation of angular masses many inches in size and many pounds in weight. The production in the middle of summer of the intense cold which is thus in-

dicated, is a puzzle philosophers have been unable to solve.

Of the actual Quantity of Water that is evaporated and condensed over the Globe.—Before we close the subjects of evaporation and condeusation, it remaius to make a few observations on the actual quautity of water that is evaporated and condensed over the globe.

From the principles we have stated, it will appear that the quantity of water evaporated and condensed over the globe, may be supposed to vary with the meau temperature, and consequently with the latitude. The following table shows the general truth of this supposition, and that the average quantity of rain diminishes from the Equator to the Poles. In fact a much larger quantity of rain must fall in the Equatorial than in the Polar regions, as is sufficiently proved by the magnitude of the rivers within the Tropics; for the size of the rivers of course depends on the quantity of the rain, the rivers being the conduits along which a certain portion of the precipitated water is borne to the sea.

TABLE.

	Inches.
Uleaborg	13·5
Petersburgh	16, 17·5
Paris	19·9
London	*20·7, †22·2, ‡25·2
Edinburgh	22, 24·5, §26·4
Mean of Carlsruhe, Manheim, Stuttgard, Wurtzburg, Augsburg, and Regensburg, (Schow)	25·1
Epping	27·0
Bristol	29·2
England (Dalton's mean)	31·3
Liverpool	34·1
Manchester	36·1
Rome	39·0
Lancaster	39·7
Geneva	42·6
Penzance	44·7
Kendal	53·9
Mean of twenty places in the lower valleys at the base of the Alps	58·5
Great St. Bernard	63·1
Vera Cruz	63·8

* Dalton. † Daniell. ‡ Howard. § Adie.

	Inches.
Keswick	67·5
Calcutta	81·0
Bombay	82·0
Ceylon	84·3
Adam's Peak, ditto	100·
Coast of Malabar	123·5
Leogane, St. Domingo	150.*

In this table, the names of the places to which it refers are arranged progressively according to the amount of rain that falls in each place; and though the progression exhibits great irregularities, yet the table fully establishes the general decrease of rain with the increase of distance from the Equator.

Sir John Leslie has shown that if all the aqueous vapour which can at any time be held in solution by the whole atmosphere, were at once precipitated on the earth in the form of rain, it would not be more than about five inches in depth: now as in the course of a year, many times this quantity of rain falls from the atmosphere, its replenishment of course must depend on evaporation, of which evaporation we may thus infer the general amount. With regard to the quantity of rain which descends annually on the entire surface of the earth, we want the means of forming an estimate: though there is no proof that this quantity is subject to any material difference. The distribution indeed as we have seen, diminishes with the increase of latitude and varies according to numerous local peculiarities, some of which have been pointed out in the preceding paragraphs. Often also, no doubt for the wisest purposes, the same place is liable to great fluctuations in the annual amount of rain, or at least in the times of its precipitation. Yet all these variations oscillate within certain limits, and scarcely affect the mean quantity proper to the place; thus showing that the distribution of rain obeys the same laws which regulate the more fixed operations of nature.

Of the whole water condensed upon the surface of the earth, a certain portion of course enters into the soil. The depth to which such water sinks, is determined by the declivity of the surface, by the nature of the inferior strata,

* From the Encyclopædia Metropolitana. Article "Meteorology," p. 123.

and by other circumstances; but usually, after a greater or less period and range of circulation, the water again makes its appearance in open day, in the form of Springs. The conjunction of springs and the occasional addition of a portion of rain water, which is neither immediately absorbed by the soil, nor evaporated, constitute brooks and rivulets; these again uniting, in their progress from the higher and interior parts of the countries where this water has been deposited, form the larger rivers; which, after dispensing innumerable benefits to the inhabitants of the plains in their course, finally discharge their superfluous waters into the ocean. As the origin of the superfluous water which flows from the rivers to the ocean, is thus unquestionably derived from the vapour condensed in the interior of the countries where the rivers originate, it follows that in every country where there are rivers, condensation must surpass evaporation. That is to say, a large proportion of the water condensed on the land must have been evaporated not from the land, but from the neighbouring ocean.

The relative proportions of the water condensed from the atmosphere, and of the water evaporated from the earth vary exceedingly in different countries. Such indeed is the amount and variety of the differences, that it is impossible to estimate them: though it is probable that in the same country, the proportions are nearly constant; or, at least, that there is a mean proportion, about which the differences oscillate within trifling limits. In this country Dr. Thomson has estimated that taking the whole of Great Britain together, the mean fall of rain amounts in the course of a year to 36 inches, the dew being included (which is considered to amount to about four inches); and that the quantity of water evaporated is about 32 inches. Consequently, the excess of four inches must be supposed to go to supply the springs and rivers; and as these four inches are thus not taken up again by evaporation from the land, they must be drawn from the seas that encircle our shores.* These

* On heat and electricity, p. 266. It is proper to observe, that this estimate differs considerably from a previous estimate of Dr. Dalton, who fixes the proportion of water flowing off by the rivers, in England and Wales, at thirteen inches. It is probable that the truth lies somewhere between the two estimates.

estimates of the water that is condensed and evaporated in Great Britain, can only be viewed as rude approximations; and even admitting them to be correct, they could scarcely be applied with any advantage to an inquiry into the actual condensation and evaporation in other countries or climates, which in all instances must be determined by observation and experiment.

Before we quit this subject, perhaps it may not be amiss to endeavour to convey to the general reader some still more definite notion of the enormous quantity of water which falls from the atmosphere to the earth. Let us suppose an area of nine square miles, which is considerably less than the area occupied by London, and that in the course of the year all the rain which falls in this area, if it stagnated and no evaporation took place, would cover the earth to the depth of two feet, which is about the quantity as we have seen, that annually falls in London. According to these suppositions, there must fall in London no less than 59,584,084 hogsheads of water in the course of the year; or 163,244 hogsheads daily, the whole of which must have been dissolved in the atmosphere, or suspended in the form of clouds, over the limited space of nine square miles.

Fourthly. *Of the Distribution of Heat and Light in their latent and decomposed Forms through the Vapour of the Atmosphere; and of the Effects of that Distribution.*—The general distribution of heat and light in their latent form through the vapour of the atmosphere, seems to follow the same laws as the distribution of sensible heat formerly explained. That is to say, the distribution of these forms of heat and light decreases from the Equator toward the Poles. The most remarkable effects of the distribution of latent heat have already been incidentally mentioned, and need not be here repeated. We shall therefore proceed to consider the particular distribution of electricity and of the decomposed forms of light in the vapour of the atmosphere, and the effects of this distribution.

Of the Relations of Electricity to the Vapour of the Atmosphere.—Atmospheric air when perfectly dry and pure, is one of the most complete non-conductors of electricity that are known. Whether water in the state of vapour possesses similar non-conducting properties does not appear to be

satisfactorily established. But the non-conducting powers of aqueous vapour must be very considerable, otherwise since the atmosphere is never entirely free from vapour, electrical insulation could not take place. On the other hand, when vapour assumes the form of water, the water instantaneously becomes a conductor of electricity. Hence a mass of visible vapour or cloud, when floating in a mixed atmosphere of air and vapour, is perfectly insulated and becomes capable of electrical accumulation. Now the phenomena arising from the equalization of such derangements of electrical distribution, are lightning and thunder. Lightning and thunder therefore are nothing either more or less, than the phenomena of electricity on a large scale; that is to say, a cloud and the earth, or two clouds, become surcharged with two opposite forms of electricity, and thus represent the interior and the exterior coatings of an electrical jar similarly surcharged; the intervening and non-conducting air is represented by the interposed and non-conducting glass, while the lightning and the thunder are the spark and the explosion caused by the union of the two electricities. If the reader bear in mind this analogy, it will enable him to understand the whole electrical phenomena of the atmosphere.

The distribution of electricity, like the distribution of heat and light, decreases from the Equator toward the Poles. Thus in intertropical countries alone, are the effects of this energetic agent displayed in all their power; there, thunder storms are quite terrific, and far surpass anything of which those, who have not witnessed them, can form a conception. In temperate climates the effects of atmospheric electricity are usually most severe in the summer, and their severity is greater in mountainous districts than in plains. Yet even under these circumstances, they are much subdued as compared with what takes place between the Tropics; while in the Polar regions electrical phenomena are still less striking.

Notwithstanding however that the general distribution of electricity in the atmosphere evidently follows the general distribution of sensible heat, it is a remarkable fact, that whenever electrical phenomena are more than ordinarily vehement, they are accompanied by some unusual appear-

ance of cold. Thus the alarming descents of hail formerly noticed, which occur most generally in temperate climates, have in nearly every instance been attendants of violent thunder storms. Snow too is almost always highly electric. These and many other circumstances connected with the great and sudden production of cold in the higher regions of the atmosphere, during the display of electrical agency, cannot in the present state of our knowledge, be explained. For example, whence in the middle of summer, arises that instantaneous development of extreme cold, which occasionally produces the terrific hailstorms above alluded to? At present the answer does not appear. Whether the principles advanced in the present volume be capable of solving the difficulty, time must determine.

With respect to the sources of the electricity of the atmosphere there have been many opinions. It was formerly maintained, that electrical excitement does not arise from the mere evaporation and condensation of water; but that in order to produce such excitement, there must always be some chemical combination or separation.* This opinion however, has been recently questioned; though it is admitted that electrical excitement is very frequently the result of the chemical changes which often accompany the evaporation alone, of water. During combustion also, there is an ample evolution of electricity; the burning body giving out negative, the oxygen positive electricity. In like manner, the carbonic acid sent forth during vegetation is charged with negative electricity; and at the same time the oxygen, as is most likely, is charged with positive electricity. Derivation from these sources has been deemed quite sufficient to explain the very large quantities of electricity which are so often accumulated in the clouds. It is however probable that there are yet other causes, or at least one other cause, on which, in numerous instances, this accumulation may still more immediately depend. We allude to a supposed combination of oxygen with the vapour of the atmosphere. For reasons which we cannot here detail, our opinion is, that these supposed combinations of aqueous vapour with oxygen, more than any other cause

* Pouillet, Elémens de Physique expérimentale, et de Météorologie. Tom. ii. p. 823.

whatever, are in some way concerned with the phenomena of atmospheric electricity. See Appendix.

The *Aurora borealis* is a phenomenon also supposed to have some connexion with electricity, though its precise nature is involved in considerable obscurity. The phenomena evidently indicate currents of some kind; and if the light be electrical, we can only suppose such electrical currents to take place in an imperfectly conducting medium. That is to say, if the phenomena as some contend, exist in the lower regions of the atmosphere, luminous electrical currents can be produced only by water in the liquid state: if the phenomena exist in the higher regions of the atmosphere as at present is supposed, such currents may depend on the extreme tenuity of the atmosphere in these higher regions. Our own opinion is, that at different times the aurora borealis exists at different heights in the atmosphere, and consequently may depend on both these causes.

The phenomena arising from the decomposition, refraction, and reflection of light by the vapour of the atmosphere are not less striking and important, than the phenomena produced by electricity. To such effects on light by the atmospheric vapour, we owe not only the cærulean tint of the sky and all the splendid colouring of the clouds, but the beneficial morning and evening twilight, nay even the light of day itself. "Were it not," says Sir J. Herschel, "for the reflecting and scattering power of the atmosphere, no objects would be visible to us out of direct sunshine, every shadow of a passing cloud would be pitchy darkness; the stars would be visible all day, and every apartment into which the sun had not direct admission would be involved in nocturnal obscurity." Again, to use the words of the same author in speaking of twilight,—"After the sun and moon are set, the influence of the atmosphere still continues to send us a portion of their light; not indeed by direct transmission, but by reflection upon the vapours and minute solid particles which float in it, and perhaps the actual material atoms of the air itself."* Such are the beautiful phenomena, and the important results, of the action of the vapour of the atmosphere on light. It remains to direct attention to a few others of a similar character,

* Treatise on Astronomy, p. 33.

and produced by the same causes; but of less frequent occurrence, or of less consequence in the economy of nature.

The first of these minor phenomena which we shall notice is the Mirage; a phenomenon depending partly on the vapour of the atmosphere, and partly on the intermixture of strata of air of different temperatures and densities. The mirage is not unfrequent in level countries, when their surface is strongly heated by the sun's rays, and evaporation results from the continuance of the heat. The mirage assumes the appearance of a sheet of water, often exhibiting the reflected or inverted images of distant objects. In Egypt and in the neighbouring sandy plains, where the mirage is very common, the illusion is at times so perfect, that travellers can hardly be convinced of the non-existence of what they imagine they see.* The phenomena are quite explicable on well known optical principles.†

Nearly allied to the mirage, is the appearance termed Fata Morgana, which is occasionally witnessed in the Straits of Messina. There are many similar phenomena, all of them owing to the refraction of light by media of various densities.

The next class of similar phenomena, are the effects produced on light by crystals of ice floating in the atmosphere, or by visible vapour. The angular forms of the crystals of ice, by determining the rays of light in different directions, give origin to various eccentric halos; which rays, by their united intensities, particularly where they cross one another, occasionally produce conspicuous masses of light, denominated parhelia and paraselenes, or mock suns and mock moons. Visible vapours consisting of water in the fluid state, likewise sometimes form halos; but such halos (when more than one exist) are always concentric, the sun or moon being in the centre. These two phenomena not unfrequently take place at the same time.

The last and most frequent atmospheric phenomenon of the general kind is that produced by the action of fluid

* See Clarke's Travels.

† See Wollaston, Philosophical Transactions, 1800, p. 239.

drops of water on light, viz. the well known phenomenon termed the Rainbow. The concomitants of the rainbow are familiar to every one: there must be rain along with sunshine. Under these circumstances, if the spectator turns his back to the sun, he sees the coloured bow projected on the opposite cloud, and displaying all the tints of the prismatic spectrum.

We are informed in the sacred narrative, that this beautiful phenomenon was chosen as a symbol to mankind of their exemption from future deluge. The sceptic may be challenged to state what pledge could have been more felicitous or more satisfactory. In order that the rainbow may appear, the clouds must be partial. Hence the existence of the rainbow is absolutely incompatible with universal deluge from above. So long therefore, as "He doth set his bow in the clouds," so long have we full assurance that these clouds must continue to shower down good and not evil upon the earth.

3. *Of the Occasional Presence of Foreign Bodies in the Atmosphere, and of their Effects.*—The foreign bodies which occasionally exist in the atmosphere, may be considered as of two kinds, viz. those which are merely suspended in the atmosphere in a state of mixture, and those which pervade the atmosphere in a state of solution.

Both in ancient and in modern times, and in various parts of the world, rain and snow have been observed to be coloured by an admixture of extraneous matters. The nature of these colouring matters has been found to be very different in different instances. Some have proved to be of vegetable origin, consisting of minute lichens and other cryptogamous plants brought from a distance by the agency of the winds, and diffused in myriads through the atmosphere. Such vegetable matters have been sometimes more or less red: whence those imagined showers of blood we read of as producing so much popular excitation. In other instances the colour has arisen from earthy and metallic matters in a state of very fine powder; and in this case their descent has been usually accompanied by violent electrical phenomena, similar to the phenomena which almost always attend the descent of Meteoric stones

or Aerolites, to which perhaps earthy and metallic showers are nearly allied.

Of the falling of stones from the atmosphere, there can now be no doubt; though the origin and the nature of these stones are very obscure, and indeed cannot in the present state of our knowledge be explained. There have been various opinions on the subject. Some considering aerolites to be the productions of our own planet, have viewed them as masses projected from volcanoes to a great height and distance in the atmosphere; or as formed by the agglutination of the earthy and metallic powders from volcanoes. Others ascribing to aerolites quite a different origin, have viewed them as fragments scattered through space, which happening to come within the sphere of our earth's attraction, have been determined to its surface.

Although we are thus uncertain regarding the origin of aerolites, or their use in the economy of nature; it now seems by innumerable observations to be completely established, that aerolites, while in the higher regions of the atmosphere, are often in a state of intense ignition. They there assume the form of brilliant meteors, which as they approach the earth, burst with a loud explosion, followed by a shower of stones. These stones generally exhibit evident marks of fusion; and many of them have been picked up while still warm, so as to leave no doubt of their being real aerolites. It is singular too, that the composition of aerolites is in some degree peculiar. They invariably contain, either iron, or cobalt, or nickel, or all these three metals, in union with various earthy substances. Aerolites have been found of every size, from that of a few grains to the weight of several hundreds of pounds; for of this weight are some of those isolated masses of iron seen in different parts of the world, and which are generally allowed to be of meteoric origin.

Intermediate as it were, between substances suspended and substances dissolved in the atmosphere, are those matters whatever their nature may be, which have been known to spread as a haze over large districts, and have been termed "Dry Fogs."

In the year 1782, and still more in the year following, a remarkable haze of this kind extended over the whole of Europe. Seen in mass this haze was of a pale blue. It was thickest at noon, when the sun appeared through it of a red colour. Rain did not in the least degree affect it. This haze is said to have possessed drying properties, and to have occasionally yielded a strong and peculiar odour. It is also said to have deposited in some places a viscid liquid, of an acrid taste and of an unpleasant smell. About the same time there were, in Calabria and in Iceland, terrible earthquakes, accompanied by volcanic eruptions. These earthquakes and eruptions were supposed to have been connected with the haze. Indeed it has been generally remarked, that such a condition of the atmosphere has been usually preceded by an earthquake, either in the same or in some adjoining country. The dispersion of this haze in the summer of 1783 was attended by severe thunder storms. As might be expected, the general state of health has, for the most part, been deranged during the continuance of these phenomena. Simultaneously there have been epidemic diseases of various kinds. Thus, in the above-mentioned years, 1782 and 1783, an epidemic catarrh, or influenza, prevailed throughout Europe, affecting not only mankind but likewise other animals.*

The nature of the matter thus diffused through the atmosphere is quite unknown. It may, at different times, be not less various than the character of the epidemics to which it gives origin.

As an example of the extraordinary effects which foreign bodies, when diffused through the atmosphere, are capable of producing, we may mention the effects produced by Selenium, when, that substance in combination with hydrogen, is diffused as a gas through the air, even in the most minute quantity. The effects of this gaseous combination of selenium with hydrogen are thus described by the celebrated chemist, Berzelius, its discoverer. "In the first experiment which I made on the inhalation of this gas, I conceive that I let up into my nostrils a bubble of gas, about the size of a small pea. It deprived me so completely of the sense of smell, that I could apply a bottle of concen-

* See Article "Influenza," in the Encyclopædia of Practical Medicine.

trated ammonia to my nose without perceiving any odour. After five or six hours, I began to recover the sense of smell, but a severe catarrh remained for about fifteen days. On another occasion while preparing this gas, I became sensible of a slight hepatic odour, because the vessel was not quite close; but the aperture was very small, and when I covered it with a drop of water, small bubbles were seen to issue about the size of a pin's head. To avoid being incommoded by the gas, I put the apparatus under the chimney of the laboratory. I felt at first a sharp sensation in my nose; my eyes then became red, and other symptoms of catarrh began to appear, but only to a trifling extent. In half an hour, I was seized with a dry and painful cough, which continued for a long time, and which was at last accompanied by an expectoration, having a taste entirely like that of the vapour from a boiling solution of corrosive sublimate. These symptoms were removed by the application of a blister to my chest. The quantity of Seleniuretted Hydrogen Gas, which on each of these occasions entered into my organs of respiration, was much smaller than would have been required of any other inorganic substance whatever, to produce similar effects."*

As we have already stated, selenium is for the most part found in association with mineral sulphur. Selenium is also, like sulphur, a volcanic product. Now, though we can hardly imagine the possibility of the diffusion of selenium through the atmosphere in combination with hydrogen, selenium may be so diffused in some other form of combination, which may produce effects analogous to those of seleniuretted hydrogen. We do not mean to assert that the diffusion of any such substance really takes place. Our intention is merely to show, that a small quantity of an active ingredient, like selenium, is sufficient to contaminate the atmosphere over a wide extent of country. Such a substance being ejected from the crater of a volcano during an eruption, or through a crevice in the earth during an earthquake, may thus produce an epidemic disease. Nor is it improbable that many epidemics, particularly those of a catarrhal kind, have so originated.

The matters occasionally diffused through the atmosphere,

* Annals of Philosophy, Old Series, vol. xiv. p. 101.

which appear to be in a state of solution, are not often perceptible by our senses; unless in some cases, perhaps, by the sense of smell.

As an instance of the presence of such bodies in the atmosphere, we may mention a very remarkable observation which occurred to the writer of this treatise, during the prevalence of epidemic cholera. He had for some years been occupied in investigations regarding the atmosphere; and for more than six weeks previously to the appearance of cholera in London, had almost every day been engaged in endeavouring to determine, with the utmost possible accuracy, the weight of a given quantity of air, under precisely the same circumstances of temperature and of pressure. On a particular day, the 9th of February, 1832, the weight of the air suddenly appeared to rise above the usual standard. As the rise was at the time supposed to be the result of some accidental error, or of some derangement in the apparatus employed; in order to discover its cause, the succeeding observations were made with the most rigid scrutiny, but no error or derangement whatever could be detected. On the days immediately following, the weight of the air still continued above the standard, though not quite so high as on the 9th of February when the change was first noticed. The air retained its augmented weight during the whole time these experiments were carried on, namely about six weeks longer. The increase of the weight of the air observed in these experiments was small, but still decided and real. The method of conducting the experiments was such as not to allow of an error, at least to an amount so great as the additional weight, without the cause of that error having become apparent. There seems therefore, to be only one mode of rationally explaining this increased weight of the air at London in February, 1832; which is, by admitting the diffusion of some gaseous body through the lower regions of the atmosphere of this city, considerably heavier than the air through which that gaseous body was diffused. About the 9th of February, the wind, which had previously been west, veered round to the east, and remained chiefly in that quarter till the end of the month. Now, precisely on the change of the wind, the first cases of epidemic cholera were reported

in London, and from that time the disease continued to spread. That the epidemic cholera was everywhere the effect of a peculiar condition of the atmosphere, is more perhaps than can be safely maintained; but reasons which have been advanced elsewhere, lead the writer of this treatise to believe, that the disease termed cholera was in London owing to the same matter which produced the additional weight of the air. The statement of these reasons here would be quite out of place; it is enough to say, that they are principally founded on remarkable changes in certain secretions of the human body, which during the prevalence of the epidemic, were observed to be almost universal; and that analogous changes have been observed in the same secretions of those, who have been much exposed to what has been termed Malaria. The foreign body therefore, diffused through the atmosphere of London in February, 1832, was probably a variety of malaria, a subject on which we shall be very brief.

In districts partially covered with water and having a luxuriant vegetation, such as marshes and fens, particularly in warm countries, or in colder countries at seasons of the year when the sun is most powerful, noxious exhalations arise whose nature differs perhaps in some degree according to the locality. Such exhalations have received the general name of Malaria, and are well known to be the fertile source of various diseases, more or less of the intermittent febrile type. In cold and in temperate climates, these diseases for the most part assume the character of regular ague, or of rheumatism; but on approaching to and within the Tropics, malarious diseases appear as the more formidable remittent and continued fevers, the well-known scourges of hot climates.

With respect to the nature of the exhalations denominated Malaria, our knowledge is very imperfect. Evidently, they are in some way connected with vegetation; not however with vegetation living and in a state of growth, but with vegetation in a state of decay. It has therefore been thought likely, that these exhalations contain some gaseous body, composed chiefly of hydrogen and carbon. Their effect may arise from a gaseous compound of this description, though no such compound is at present known; and the

probability is, that malaria occasionally owes its properties to other elements, besides the hydrogen and carbon disengaged from decaying vegetables.

We have thus endeavoured to give a concise statement of that wonderful assemblage of Laws, of Adaptations, and of Arrangements, which viewed together constitute what we term Climate; and which, as affecting the welfare of the denizens of this globe, undoubtedly are not surpassed in interest or importance by any other arrangements throughout the whole of nature. Of the innumerable suns and planets which may occupy the boundless expanse of the universe, we feel not the influence; even their existence scarcely obtrudes itself on our notice. But the light and the heat of our own sun, and the wind and the rain of our own atmosphere, are alike the intimate concern of every organized being on this earth, from Man the Lord of its creation, down to the humblest plant that drinks the dew. The subject of Meteorology therefore, in all ages and countries, has attracted the especial attention of mankind. In ruder states of society, empirical prognostics founded on the aspects of the clouds, on the movements of animals, and on other incidental occurrences, formed the study of those who pretended to a fore-knowledge of the weather; while electrical phenomena were objects of superstitious awe. In modern times much of this wonder and uncertainty has been removed. The gloom or the clearness of the air, the mists and the halos of a stormy sky, the restlessness and clamour of animals, are now referred simply to that overcharge of moisture, and to that unequal distribution of electricity, which precede a fall of rain. Nay, the very thunderbolt has been arrested in its course, and being no longer an object of amazement, has been divested of half its terrors.

But is this advance in knowledge calculated to lessen our veneration for the great Author of Nature, or to derogate from his wisdom and his power? On the contrary, our estimate of both must be greatly increased. Of the Deity, infinite as he is, and dwelling in infinity, we finite beings can form no conception. What little therefore, we do know of Him, we know nearly altogether from his works. Consequently whoever has most studied His works,

will be the best qualified—nay will be alone qualified, to form an adequate conception of Him. Thus to measure, to weigh, to estimate, to deduce, may be considered as the noblest privileges enjoyed by man; for only by these operations, is he enabled to follow the footsteps of his Maker, and to trace His great designs. Instructed by these operations, he sees and appreciates the wisdom and the power, the justice and the benevolence, that reign throughout creation; he no longer gazes on the sky with stupid wonder, nor dreads the thunderbolt as manifesting the wrath of a vengeful Deity.

The constituents of climate, even imperfectly as they can be understood by us, are seen to be adjusted and arranged in a manner so surprising, that, to those who admit the existence of design, they require only to be stated and apprehended in order to their being received as additional proofs of that great argument. Where all are great, and splendid, and good, selection is precluded; but the circumstances accompanying the distribution of water over this globe, more perhaps than any other, arrest our notice as indicative of design. Leaving out of view the other properties of water, on what other supposition besides that of design, can we account for all these astonishing properties, on which depend its evaporation and diffusion through the atmosphere—its subsequent condensation, not at once in the form of water or of ice, but in the intermediate state of clouds—its colour and lightness when in the state of snow—its power of refracting light and of conducting electricity—in short, all the numerous, minute, and comprehensive qualities displayed by this highly elaborated fluid? These qualities together form such a union of adaptations and arrangements, each most successfully accomplishing a particular purpose, and apparently directed to and designed for that purpose, that to doubt the agency of design would seem impossible. Yet some men's minds are so warped, that they either cannot or will not be persuaded of the existence of design; but asserting the omnipotence of the laws of nature, they forget Him who framed these laws, and are reluctant to give credence to His being, or to His power. To such persons, Meteorology offers one or two exclusive arguments, which, at the risk of

being accused of tediousness and unnecessary repetition, we shall urge briefly in this place.

The great Author of Nature, as we have before said, has chosen to act agreeably to certain established laws, by which He is invariably guided. Some of these laws we are able more or less to comprehend, and we can refer them to more general principles. Others are beyond our comprehension; we see only their effects, and even these effects are most imperfectly revealed to us. As instances of the laws of nature which it is in our power to refer to general principles, may be mentioned the currents in the ocean and in the atmosphere, by which the equilibrium of temperature over the globe is maintained. These currents we know, are strictly referable to hydrostatic and pneumatic principles. The argument of design, which is deducible from these principle, rests therefore, not so much on the principles themselves, as on their application precisely where they are requisite. On the other hand as we stated at the commencement of this treatise, our knowledge of the laws of chemistry is founded solely on experience; so that our acquaintance with them is very defective: for in very few instances are the laws of chemistry referable to the laws of quantity; and even when they can be so referred, it is only in a manner very imperfect. But though we do not comprehend the laws of chemistry, we see that many of them, perhaps all in so far as they are intelligible to us, are entirely consistent with each other; and are as uniform in their operation as those laws which obviously depend on mechanical principles, or on the great principle of gravity. Thus the laws that all bodies are expanded by heat and are contracted by cold—that chemical substances do not mix, but always combine in certain proportions and in no others, —are general laws to which there are so few exceptions, that in the operations of nature and in the common intercourse of mankind, they are calculated on as invariable and necessary results, with not less consequence than that a heavy body will fall to the earth, or that two and two make four. We have selected these two laws of chemistry, partly from their general and indisputable character, and partly that the force of the argument which follows may be more conspicuous.

All bodies are expanded by heat and are contracted by cold.—If water had not constituted an exception to this law, though all its other properties had been the same as they now are, long before this time as we have seen, half the water on the globe would have been converted into ice, and the existence of organized beings would have been physically impossible.

All chemical substances combine in certain proportions, and in no other.—If air had been formed according to this law, every thing else being the same as at present, long before this time half of the air in the atmosphere would have been contaminated and rendered unfit for the support of animal life. In order therefore that water might not be frozen, and that air might not become irrespirable, laws must be infringed—and they are infringed; infringed too, precisely where their infringement both in kind and degree, is indispensably necessary to organic existence. Now we appeal to the most inflexible sceptic regarding the argument of design and ask him on what other principle, unless that of express adaptation and design, can two such general laws have been infringed, exactly in those instances in which their infringement is wanted and nowhere else? Of the sophistry by which the evasion of this plain question may be attempted, we are quite ignorant. But we cannot resist the conviction, that one purpose of the arrangement has been to confound the presumptuous sceptic, who is thus perpetually reminded of the infringement of his boasted "laws of nature," by the very water he drinks, and by the very air he breathes.

With respect to the foreign bodies in the atmosphere, which have been treated of in the last section, it remains to observe that though of very opposite characters they have yet this resemblance; that they all apparently exist less on their own account, than as being the inevitable results of general laws established for a higher purpose. Such results of general laws may be considered as analogous to the coldness and darkness which necessarily prevail around the poles, from the earth's position in relation to the sun; and they have been alike permitted, not because they could not have been avoided or removed, but in the language of Paley before quoted, "because the Deity has

been pleased to prescribe limits to his own power, and to work his ends within these limits."

Man, forgetting how insignificant he is, and how limited his utmost knowledge, is too apt to measure Omnipotence by the standard of his own narrow intellect; and to be guided by his own selfish feelings, in judging of the extent of Divine benevolence. That this earth, a minute fraction as it is of a great and wonderful system should be amenable to the general laws by which the whole system is governed, is at the least exceedingly probable. Of such general laws, of their changes, of their aberrations, or of their influences, we, situated in this extremity of the universe, cannot see the object. What therefore appears to us anomalous or defective, may in reality be parts of some great cycle or series, too vast to be comprehended by the human mind, and known only to beings of a higher order or to the Creator himself. So again, amidst the desolation of the hurricane or of the thunder-storm, in the settled affliction of malaria and in the march of the pestilence, the goodness of the Deity is impugned, his power even is regarded doubtfully. But what in truth, are all these visitations but so many examples of the "unsearchable ways" of the Almighty; "He sits on the whirlwind, and directs the storm:" a hamlet is laid waste, a few individuals may perish, but the general result is good, and pestilence with all its train of evils disappear. Nay, however inscrutable the object of the deadly malaria itself, do we not see one end which it serves, namely to stimulate the reasoning powers and the industry of man? By his reason, man has been guided to an antidote beneficently adapted for his use, which has stript malaria of half its terrors. By his industry, the marsh has been converted into fertile land, and disease has given place to salubrity.

When therefore we duly consider all these things; when we reflect also on the number, the properties, the various conditions of the matters composing our globe; the wonder surely is, not that a few of these matters occasionally exist as foreign bodies in the atmosphere, but that others of these matters are not at all times diffused through it, and in such quantity as to be incompatible with organic life. Thus the original constitution of the atmosphere, and the preservation

of its purity against all these contaminating influences, may be viewed as the strongest arguments we possess in demonstration of the benevolence, the wisdom, and the omnipotence of the Deity: benevolence in having willed such a positive good, wisdom in having contrived it, and omnipotence in having created it and in still upholding its existence.

CH. VII.—OF THE ADAPTATION OF ORGANIZED BEINGS TO CLIMATE; COMPREHENDING A GENERAL SKETCH OF THE DISTRIBUTION OF PLANTS AND ANIMALS OVER THE EARTH, AND OF THE PRESENT POSITION AND FUTURE PROSPECTS OF MAN.

IN the general survey of climate and of its reference to organization given in the preceding chapter, we have seen on the one hand, that by a series of wonderful expedients, the climate or temperature of the greater portion of the earth's surface has been so equalized, as to be brought within the range of organic existence. On the other hand, we shall find that by a series of expedients not less wonderful, organic existence has been so diversified and extended, as to include all the possible varieties of soil and climate. Hence the arrangement taken altogether, presents us with such extraordinary instances of mutual adaptation, as to admit of being explained only on the supposition that all these expedients form parts of the same magnificent Design; while the infinite variety where there might have been an unbroken sameness, must be considered as equally indicative of the Benevolence and the Power of the Designer.

Next to Climate, the circumstance in which organized beings are most immediately concerned is Soil; a subject already alluded to, but which it will be necessary to illustrate a little further before we proceed.

The soil is that collection of matters, more or less in a state of comminution, which, immediately covering the general surface of the earth, fills up its minor inequalities, and rounds off its asperities. On this layer of comminuted mineral substances and organic remains, all vegetables and

animals, at least all land animals, depend for their subsistence; and if there ever was a time when the materials composing this globe were collected into solid masses, it is evident that such a condition must have precluded the existence of the greater number of the plants and animals, by which the earth's surface is now occupied.

The formation of the soil has apparently been a work of time, and the result of the gradual attrition of the solid materials composing the crust of this globe. Hence the formation of the soil has probably been always progressive, and is still going on. Besides this gradual attrition, the harder materials of our globe seem to have suffered much disintegration during those periodic convulsions formerly mentioned. By the same convulsions also, the different comminuted materials have evidently been mixed and scattered, and finally deposited over the surface of the whole earth, so as to give occasion to that infinite variety which everywhere prevails.

The foregoing remarks naturally lead to the conclusion, that the character of the soil will generally agree with the character of the rocks composing the crust of the earth; and this inference is correct. The more common ingredients in rocks are silex, alumina, lime, magnesia, and iron; and these mineral matters actually constitute the greater bulk of every soil. The remaining matters consist of more or less of various other earthy and saline principles, and of vegetable and animal remains.

After these general observations on soils, we come to the proper subject of this chapter, which we shall consider under the three following sections:—Of the Distribution of Plants over the earth;—Of the Distribution of Animals over the earth; and,—Of the present Condition and future Prospects of Man.

§ 1.—*Of the Distribution of Plants over the Earth.*

From what has been premised, it will be readily understood that Soil and Climate are the two great and immediate causes, by which vegetable and animal existence are likely to be affected. We shall therefore in the first place treat,

1. *Of the Differences of Vegetation as liable to be influenced by Soil and by other minor Local Circumstances in the same Climate.*—The most incurious observer in travelling through a country, must be struck with the different vegetation that prevails in different parts of the country; and with the effects this difference produces on the manners and on the health of the inhabitants. Thus, in some parts of England, the Apple and the Pear are seen growing spontaneously in every hedge-row; while in other parts, apple and pear trees will not flourish, even with the utmost care. Some situations are favourable to the Oak, others to the Beech, others to the Elm. Accordingly these well-known and beautiful trees predominate in some districts, almost to the exclusion of every other, and thus become the chief peculiarities of their scenery.

These are familiar examples of partial changes among the larger vegetables of a country, while the general vegetation is supposed to remain nearly the same. Between such partial change and the complete establishment of a peculiar vegetation, there exists among different localities, every possible shade of diversity. Many of these differences in vegetation are obviously connected with differences in soil and in situation. Thus, some plants will thrive only on a calcareous soil; as a few of the Orchis tribe in our own country, and the Teucrium montanum in Switzerland. Others, like the Salsolas and the Salicornias, will grow only in salt marshes. Some plants flourish in sea water, some in fresh; while to others again, water, at least in excess, is so prejudicial, that they can exist nowhere, unless on bare rocks or in arid deserts. Mountainous situations are most favourable to the increase of some plants; while others abound in plains. The larger number of plants prefer sunshine, but some are most vigorous in the shade; and others are so impatient of light, that they are found only where there is absolute darkness. There are besides, parasitic plants, like the Mistletoe, whose nourishment is derived from the plants to which they are attached. In short, the varieties in the nature of plants are countless, nor is the enumeration of them requisite. The slightest survey is more than enough to show the wonderful arrangements which have been made to ensure the clothing of every

part of the earth's surface with vegetable organization. There is not a soil however barren, nor a rock however flinty, that has not its appropriate plant; which plant has no less wonderfully found its way to the spot adapted for it, nay will perish if removed elsewhere. Saline plants for instance, will grow only where saline matters are abundant; plants of the marsh, and of the bog, flourish only in marshy and boggy ground; those of the parched desert and of the cloudy mountain, each in its fitting locality. Thus the soil and its occupant seem to have been made for each other; and hence one source of that astonishing variety exhibited in nature.

There are still more remarkable deviations among the plants of different countries remote from one another, even where the circumstances of climate and of soil are in every respect alike. The plants of the Cape of Good Hope for instance, differ exceedingly from the plants of the south of Europe, though the climate and much of the soil be not dissimilar. Often on the same continent, nay on the same ridge of mountains, the plants on the opposite sides have no resemblance. "Thus in North America, on the east side of the rocky mountains, Azaleas, Rhododendrons, Magnolias, Vacciniums, Actæas, and Oaks, form the principal features of the landscape; while on the western side of the dividing ridge, these genera almost entirely disappear, and no longer constitute a striking characteristic of the vegetation." *

In general, the plants of America are different from the plants of the old world, except towards the north; where as might be expected from the near approximation of the two continents, many individuals are common to both. The plants of islands, and those growing in isolated situations, are often quite peculiar. The plants of New Holland for instance, with comparatively few exceptions, differ from the plants of all the rest of the world; and "of sixty-one native species in the little island of Saint Helena, only two or three are to be found in any other part of the globe." † Such facts are quite inexplicable on any known principles;

* Lindley's Introduction to Botany, page 489.

† See Principles of Geology, vol. ii. by C. Lyell, who has treated this interesting subject in detail. To Mr. Lyell we are indebted for many of the following facts.

and are calculated to excite a more than ordinary degree of attention, as being solely referable to the will of the Great Creator; who has chosen to provide infinite diversity, where all might have been uniform and monotonous; and has thus rendered more conspicuous His wisdom, His power, and His goodness.

2. *Of the Influence of Climate on Vegetation.*—The climate of a place, as has been before shown, independently of minor local causes, is influenced chiefly by the two following circumstances: the Latitude of the place, in other words the relative amount of heat and light which it receives from the sun;—and its Height above the surface of the sea; by which circumstance of elevation, the heat received from the sun is liable to be varied at least as much as by latitude; but the variation is according to other laws than those which depend on mere latitude, indeed according to laws which vary in different latitudes.

Every one is acquainted with the general fact of the difference between the plants of warm and those of cold countries, between the plants that grow on plains, and those that grow on mountains. Thus, "in the countries lying near the Equator, the vegetation consists of dense forests of leafy evergreen trees, Palms, and arborescent Ferns, among which are intermingled epiphytal herbs, and rigid Grasses. There are no verdant meadows, such as form the chief beauty of our northern climate; and the lower orders of vegetation, such as Mosses, Fungi, and Confervæ are very rare. As we recede from the Equator, the plants above mentioned gradually give way to trees with deciduous leaves; rich meadows appear, abounding with tender herbs; the epiphytal Orchideæ are no longer met with, and are replaced by terrestrial fleshy-rooted species; Mosses clothe the trunks of aged trees; decayed vegetables are covered with parasitical Fungi; and the waters abound with Confervæ. Approaching the Poles, trees wholly disappear; dicotyledonous plants of all kinds become comparatively rare; and Grasses and cryptogamic plants constitute the chief features of the vegetation." *

Changes not very dissimilar are observed in the vegetation at different heights on the mountains of warm cli-

* Lindley's Introduction to Botany, page 484.

mates. Thus, at the base of the celebrated Peak of Teneriffe, the plants have all the distinguishing characters of the plants of Africa. There flourish the succulent Euphorbia, the Mesembryanthema, Dracœna, &c.: also the Date palm, the Plantain, the Sugar-cane, and the Indian-fig. A little higher grow the Olive tree, the fruit trees of Europe, the Vine, and Wheat. Then succeeds the woody region of the mountain, where from the numerous springs the ground is always verdant. In that region is seen a profusion of beautiful evergreens, such as various species of Laurel, one of Oak, two species of Iron tree, an Arbutus, and several others. Next above, is the region of pines, characterized by a vast forest of trees resembling the Scottish fir, intermixed with Juniper. Then follows a tract remarkable for the abundance of a species of Broom. At last the scenery is terminated by Scrofularia, Viola, a few Grasses, and cryptogamic plants.*

The proportions which different groups of plants bear to each other, vary exceedingly in different latitudes. An interesting table given in the Appendix, slightly altered from Humboldt, exhibits the proportional amount of some natural groups of plants to the whole mass of vegetation in the successive zones, and will enable the reader to understand the relation of vegetable forms to the greater or less distance of their place of growth from the Equator. The arrangement is so obvious as scarcely to require explanation. Thus in the equatorial zone, between 10° north and 10° south latitude, the first group including Ferns, Lichens, Mosses, and Fungi, constitutes on the plains only 1-15th, but on the mountains 1-5th of the whole number of plants growing in that zone. While in the temperate zone, the proportion of the first group of plants is at least one-half of the whole number, and in the frigid zone the entire vegetation consists of plants of that group. The distribution of the other groups is equally remarkable.

From this table we learn many interesting particulars, in addition to what has been already stated regarding the distribution of plants over the surface of the globe. We may notice especially, the striking difference between the Flora of the Old and the Flora of the New World, in

* Humboldt.

corresponding parallels of latitude. These differences in a great many instances are undoubtedly referable to certain peculiarities in the climate and in the soil. But in other instances, they are obviously connected with the difference of temperature prevailing in the two continents under the same parallel. Before we proceed, let us dwell a little longer on the consideration of these beautiful arrangements.

In Tropical countries alone, beneath a vertical sun, do we see vegetation in all its glory and magnitude. There the form, the colour, and the odour of plants, are developed to the utmost; and where else could they be so developed? where else could the majestic palm rear its towering stem, and send forth its gigantic leaves? where else could we expect to find groves ever verdant, blooming, and productive? Amidst eternal summer, all this exuberance is in character: forests denuded of their leaves, and for half the year assuming the appearance of death, would in such a climate be perfectly incongruous. But in countries remote from the Equator, and in which during many months the temperature is more or less depressed, a vegetation thus incessantly active could not exist, nor would it be appropriate. Accordingly the palm tribe, and many of the more distinguishing productions of the Tropics become gradually fewer in number as we recede from the Equator, and at last give way entirely to deciduous plants; that is, to plants endued with the power of hybernating, or sleeping as it were, in the colder season, and vegetating only during the warmer portion of the year. And here we have displayed another of those admirable provisions which at once strike us irresistibly as being the effect of design! In Tropical countries, where the seasons are uniform, and where there is no cold to injure, the leaf buds of plants are without covering or protection, and are freely and confidently exposed to the atmosphere. But in climates where the seasons change, and where vegetation is liable to be suspended by the cold, the leaf buds exhibit a structure remarkably different. Developed in the latter end of summer or autumn, they are almost invariably provided with *tegmenta* or coverings, within which, during their period of torpor, they are cradled, safe from cold and from accident.

As we advance still further to the north or to the south, where the winter becomes more severe and of longer continuance, deciduous plants in their turn diminish both in number and in magnitude; and after having shown themselves under a variety of stunted forms, are at length almost entirely superseded by a few coarse grasses and lichens. Yet even here design is apparent. These hardy natives of the poles are, from the simplicity of their structure, wonderfully adapted to the climate of the region they occupy; in which alone they will flourish, and for which alone therefore they have been expressly created.

Though it be generally true that plants will grow only in the soil and climate adapted for them, yet as if intentionally to evince His power, the Great Author of nature has willed some manifest exceptions to this rule. All organized beings have been more or less endowed with the faculty of accommodating themselves to circumstances. In the larger number of plants this faculty scarcely exists, but in some it is much stronger; and in others, constituting the exceptions among vegetables, the extent of the accommodating faculty is almost incredible. In general, plants that are the natives of peculiar soils and of extreme climates, are the most impatient of change; while the natives of ordinary soils and of temperate climates have a wider range of growth. The exceptions to the rule of adaptation are chiefly among plants that are natives of such soils and climates. Thus, "the Samolus Valerandi is found all over the world, from the frozen north to the burning south; associated here with Birches and similar northern forms, and there mixed with Palms and the genuine denizens of the tropics. The number of plants however, which can thus accommodate themselves to all circumstances and climates is limited; while those which readily naturalize themselves in climates similar to their own, are on the other hand numerous. Of the latter, indeed, examples present themselves at every step. All the hardy plants for instance, of our gardens may in some sort be considered of this nature; for although they do not grow spontaneously in the fields, they flourish almost without care in our gardens. The Pine-apple has gradually extended itself eastward from America through Africa into the Indian Archipelago, where

it is now as common as if it were a plant indigenous to the soil; and in like manner the Spices of the Indies have become naturalized on the coast of Africa and the West India islands." To this property of naturalizing themselves, no doubt is to be referred in a variety of instances, the presence of the same plants in different countries. For though, as we have just now stated, the Flora of different countries is generally different, yet in almost all instances some plants exist which are found in other countries. Thus, "above 350 species are said to be common to Europe and North America; and even among the peculiar features of the Flora of New Holland, Mr. Brown recognized 166 European species. The presence of many of such strangers may undoubtedly be referred to the agency of man and other animals, to currents in the ocean, to winds, and a variety of natural causes." While "the presence of others seems inexplicable on any other supposition than that they have been created in the places where they now exist."*

Hitherto we have considered plants only in relation to the soil and to the climate in which they grow, and have not entered into details respecting all the beautiful arrangements by which their growth has been accomplished. The consideration of these arrangements belongs to the Physiologist, the Botanist, and the Geologist, with whose duties we wish as little as possible to interfere. There is however, yet one point of view, in which our argument naturally leads us to consider vegetation; namely, as forming the link by which animals are connected with the earth; in other words, as furnishing to animals the means of substances.

The circumstances which perhaps more than any other, is calculated to arrest our attention with respect to vegetable productions in general, is their vast profusion in every sense of the term, whether we contemplate their variety, their magnitude, or their number. Thus the numerous and varied plants growing in tropical climates are equally remarkable from their size, their luxuriant foliage, and the exuberance of their roots and seeds. Let us take for instance the palm tribe. It has been estimated that there are a thousand species of palms; and though the number actually known to exist is by no means so large, yet late

* Lindley's Introduction to Botany, p. 501.

discoveries seem to render the estimate not improbable. In many of the palm tribe the development of the form, and the quantity of flowers and fruit is altogether extraordinary. Among others, the species which yields the well known Cocoa-nut grows to the height of eighty feet; each plant flourishes for a century; and, during the greater part of that time, continues to produce annually at least a hundred of these large nuts. Yet the cocoa-nut species may be considered as one of the least productive of the palm tribe: for every bunch of another species, the Seje palm of the Oronoko bears as many as 8000 fruit; while a single spatha of the Date palm contains 12,000 flowers; and in a third species, the Alfonsia Amygdalina, there is the enormous number of 207,000 flowers on each spatha, or 600,000 on a single individual plant!

In superlative exuberance however, the Palm tribe must yield to the Banana, or Plantain, another inhabitant of tropical countries. The fruit of this plant is often a foot in circumference, and seven or eight inches long; it is produced in bunches containing usually from 160 to 180 fruit; and each bunch weighs from 66 to 88 pounds avoirdupois. As Humboldt has remarked, the small space therefore of 1000 square feet, on which from thirty to forty Banana plants may grow, will on a very moderate computation, afford in the course of a year 4000 pounds weight of fruit; a produce 133 times greater than could be obtained from the same space if covered with wheat and 44 times greater than if occupied by potatoes. The Orange tree may be mentioned as another instance of extraordinary fecundity; thus a single tree at St. Michael's, has been known to bear in a season 20,000 oranges fit for packing, exclusively of those damaged and wasted, amounting to at least one-third more. An example to the same effect but of a different kind is the Sugar cane, which furnishes an unlimited supply of saccharine matter in its purest form; while various roots, as those of the *Cycas Jatropa* and many others, abound equally in farinaceous matters.

As we withdraw from the Equator into the regions of hybernating plants, vegetation is seen on a much less magnificent scale; though in the temperate climates, and even where we might expect to find utter sterility, number in

some degree compensates for magnitude. Thus instead of the single stupendous tuft of the palm, we have the numerous congregated buds of our deciduous trees; instead of the gigantic and solitary grasses of the torrid zone, we have the smaller and gregarious varieties. Some of these varities, as the *Cerealia* or Corn tribe, with their myriads of seeds, give us an inexhaustible supply of farinaceous aliment; while others, as the Grasses properly so called, clothe our meadows with verdure, even to extreme latitudes, and are equally productive of matter purely herbaceous. In the warmer parts of the temperate zone, the Olive and the Vine afford the oleaginous and the saccharine principles, under a form different but not less useful than the oil and the sugar of the tropics; while in the colder parts, various seeds and hardy fruits, produce an ample store of the same valuable articles, though in a condition still further modified.

In the preceding detail we have intentionally kept out of view the existence of animals, that we might here ask the question,—Of what use is all this amazing exuberance of superfluous matter throughout the globe? The adaptation of plants to the climates in which they flourish, is evidently the work of an intelligent Creator. But can this waste of materials, and of labour, be reconciled with the same wise agency? Surely the mere existence of vegetation did not require such prodigality. Seeds for instance, need not have been enveloped in bulky fruits, nor need they have been produced by myriads; and all that foliage, all those flowers and roots, in such amazing profusion, of what use are they; why they were so created? If we regard vegetation as a thing solely adapted to climate, and existing for its own sake alone, the question scarcely admits of a rational answer. But if we consider at the same time the existence of animals, and view these superfluities as the means by which animal existence is principally upheld, every difficulty vanishes, and the splendid design of the whole wonderful scheme becomes at once apparent. We are thus brought to the consideration of animal existence.

§ 2.—*Of the Distribution of Animals over the Earth.*

Animals have been so constituted, that food is to them indispensable: they can therefore exist only where their

food has been supplied by nature. On land, at least in the warm and temperate climates, by far the greater proportion of animals derive their subsistence either directly or indirectly from the vegetable kingdom. For those animals which are themselves carnivorous, prey on vegetable feeders much oftener than otherwise; and are thus ultimately dependent on vegetables. Of the habits of animals living in the sea, and thus concealed from our view, we know still less: but in general they appear to prey on each other; the stronger as is usual devouring the weaker.

We have seen the wonderful diversities prevailing among vegetables, in different situations and climates: and it may be truly said, that the diversities among animals are not less numerous, and are even more extraordinary. Thus in every climate and soil, almost every herb has its appropriate inhabitant; some little being that comes into existence, passes its ephemeral life and dies on the same plant; to which being therefore, that plant constitutes the world. Nay in general, even different parts of the same plant have each its separate occupants, one feeding on its fruit, another on its flowers, a third on its leaves, perhaps a fourth on its mere woody core. This almost infinite diversity, and infinity of number, are principally confined to the smaller animals, or insects. As animals increase in size, the number of species as well as of individuals constantly diminishes. Thus, while there are hundreds of species of the Beetle tribe, and the individuals are countless, there may be considered to be only one Elephant: and while Shrimps are in numbers like the sand on the sea-shore, the Whale is as much a solitary species. This striking difference with regard to numbers has been considered to arise necessarily from a law of nature, and in one respect such an explanation is very obvious; but viewed in another manner, there is discovered to us an admirable evidence of design. It is clear that millions of elephants could not exist, if for no other reason, from want of food; but why should millions of beetles exist? why should these little creatures,—whose life is so transitory that it consists of little more than of being born and of dying; whose structure is so frail as to be liable to be annihilated by the slightest accident; who are everywhere surrounded by all sorts of enemies, to many

of which they constitute a natural prey;—why we ask, in spite of all these obstacles and dangers, should these insignificant animals contrive to exist in the numbers we see? No natural law surely, will explain the appearance of such multitudes. The difficulty requires another solution, and the only solution which can be offered is design—that it was so designed by the Great Author of nature. And how has he effected His purpose of multiplying to such an extent these little animals? The answer is simply by increasing their fecundity. Had beetles like elephants brought forth only one young at a time, long ere now, their race would have been exterminated; but being produced by thousands, some of the numerous offspring chance to escape, and thus the race is perpetuated.

We shall not dilate further on the arrangements which have been made for the existence and preservation of animals, but shall proceed to consider their distribution.

The distribution of animals over the earth may be conveniently treated of under the same heads as the distribution of vegetables; and first:

1. *Of the Differences among Animals dwelling in similar Situations in different Parts of the World.*—The dwelling of animals in the water is perhaps, the most remarkable as regards their localities. Now since from circumstances formerly stated, the changes of temperature are very different in the sea from what they are on land, and since most aquatic animals prey on each other, and consequently in some degree are independent of climate, the distribution of such animals over the globe follows laws materially different from those laws, by which the distribution of land animals is regulated. This variation of temperature more especially affects the distribution of animals in high latitudes; and must be taken into account at the very outset of this part of our inquiry. We shall therefore, state concisely the distribution of land animals and of sea animals apart from each other.

The distribution of land animals resembles to a certain extent the distribution of vegetables; for though animals differ from plants in being endowed with the power of locomotion, yet as the larger number of animals are dependent on vegetables for their subsistence, they are necessarily

confined to those places, where their peculiar food may be obtained. This limitation of range is most observable in the case of the smaller animals. The existence of many kinds of insects especially, is intimately connected with the existence of certain plants. In every tribe of animals however, there are species occupying very different localities. Thus in the same tribe, some species dwell on the mountains, others on the plains; some species are most numerous on the sea-coast, others live on trees, while species of the same tribe burrow in the ground. All these diversities in regard to residence, are like many besides, influenced probably by the greater or less degree in which the locality affords the means of obtaining subsistence. But in many animals, there is also a wonderful adaptation of structure to the place they inhabit; proving beyond a doubt, that the distribution of animals has been arranged by design, and that they form but a part of the great symmetrical whole of creation.

In animals living in water, the same peculiarities of habitude are observable, as in those living on the land. Thus it is perfectly known that many animals can exist in salt water, others only in fresh. Some prefer the deep and open sea, others frequent only shallow water, or the mouths of rivers. Of those that flock to the coast, some shun turbid water, others burrow in the mud. In short though the habits and adaptations of aquatic animals can be less satisfactorily ascertained, there is every reason to believe that they are at least as wonderful as the habits and adaptations of the occupants of the land.

There is an equally striking diversity in the animals as in the plants of similar localities and climates in different parts of the world. Thus in the whole world, though there are many genera common to the analogous climates on the north and on the south of the equator, yet the species are totally different. For instance, the northern hemisphere possesses the Horse and the Ass; while in the south, these species are represented by the Zebra and the Quagga. In the southern hemisphere, there also exist many species which are quite peculiar; as the Giraffe, the Cape Buffalo, and a variety of animals having the Antelope form. So likewise, the animals of the old and the new world are in

general quite distinct; unless perhaps, towards the north, where the two continents approximate, and where in consequence there are some species common to both. Thus the Elephant, the Rhinoceros, the Hippopotamus, the Giraffe, the Camel, the Dromedary, the Horse, and the Ass; also the Lion and the Tiger, and various species of Apes, Baboons, and other animals, with which we are familiar in the old world, were not found in America. On the other hand, the American species, the Lama, and the Peccari; and among carnivorous animals, the Jaguar, or American tiger; also the Agouti, the Paca, the Coati, the Sloth, and others, were equally unknown in the old world. Again the animals of New Holland differ like its vegetation, not only from all those of our continent, but from those of all the world besides. In New Holland there are more than forty species of marsupial or pouched animals, of which the Kangaroo is that with which we have become best acquainted; while everywhere else, there is hardly a known instance of a pouched animal. Nor are these differences confined to the more perfect animals. They are even more striking as we descend in the zoological scale. Thus among birds the individual species of the Parrot tribe in America, differ altogether from those of Africa; and those of Asia differ from both. The minute and beautiful family of Humming birds is peculiar to America. While the species of the common Grouse of this country is met with in no other part of the known world.

From the class of reptiles, may be mentioned the Great Saurian or Lizard tribe. Thus the Crocodile of the Nile is entirely different from the Cayman of America, and even from the Gavial of the Ganges. In the division of snakes too, the Boa of India differs from the nearly allied Python of America; and of the poisonous varieties, the Rattlesnake is peculiar to America, the Cerastes to Africa, the Hooded snake to Asia. As we have already stated, the diversities among insects are still more numerous and remarkable than among the larger animals. To enter into details would be endless, we shall therefore mention only one of the best known and widest extended of all the insect tribe, viz. our common Bee. This insect did not exist in America, or in New Holland, though it is found in all parts of the old

world; the wax and honey of Europe, Asia, and Africa being obtained from species having a close resemblance to each other.

Nor are these differences confined to land animals; the inhabitants of the waters are equally diversified. Thus the Whales of the northern ocean are quite unlike those of the south; as are the Seals, and other analogous animals in the polar regions. Different seas, also, not only when far apart, but even some which freely communicate, are often exceedingly dissimilar in their zoology. Thus the fishes of the Arabian Gulf are said to differ entirely from the fishes of the Mediterranean, notwithstanding the proximity of these seas. Nor does the remark apply only to the larger fish in these seas, but holds equally with respect to their testaceous and molluscous species.

Such are a few of the more striking facts with regard to the distribution of animals in similar climates and localities throughout the world. We now shall briefly speak,

2. *Of the Effects of Diversity of Climate on the Distribution of Animals.*—In tropical climates, the qualities of animals as well as the qualities of vegetables are developed to the utmost; producing that harmonious adaptation of all the works of nature, conspicuous indeed, in all climates, but in Tropical climates more especially. For where else than amidst the profuse exuberance of the vegetation within the tropics, could the Elephant, the Rhinoceros, the Giraffe, and other large quadrupeds find subsistence? Where else could we expect to see such birds as the Ostrich and the Cassowary? such reptiles as the Crocodile? such serpents as the Boa? To what other part of the world could the magnificent butterflies, the enormous beetles and spiders, be so appropriate? Even among the marine animals of Tropical climates, there is the same wonderful enlargement of size. Thus certain species of the Crab and Lobster, and various shell fish, often attain an enormous magnitude. Nor is there a development of size only, but of every other property in an equal degree. Countries within the tropics exhibit the most beautiful forms—the most splendid colours in nature. There in short is the most astonishing display of all those things which seem to be entirely ornamental; as for example, the singular plumage of the Birds

of Paradise—the gaudy liveries of many of the Parrot tribe—the extraordinary and varied forms and colours of many insects and shells.

Not only is there in Tropical climates an assemblage of all the concomitants of productiveness, and utility, and embellishment of every kind; in these climates, there is another, and not less marked demonstration of the power and the wisdom of the Creator. Within the Tropics, death, the last, the inevitable scene, assumes a character as new and multiform as that of the life it terminates. There, rages the implacable ferocity of the Tiger, and of the larger beasts of prey; there, the fangs of the serpent are charged with the most malignant venom; there, even the insects are as formidable as they are numerous. Nor is this intensity of the destroying power, incongruous or without an object; but evidently is in perfect harmony with the rest of creation, and with the design of the Creator. The wonderful productiveness of animals in Tropical countries, renders unavoidable some checks against their excessive increase; and in devising these checks, the great Author of Nature has displayed the same attributes which are manifest in all his other works. No one who seriously reflects, can doubt either the wisdom or the benevolence of the provision. For why are Tigers and Serpents confined to those parts of the world, where their existence is not only accordant, but where for one great purpose at least, they are even necessary? Surely such limitation could have happened only from design; and the argument is strengthened a hundred fold, when we contemplate the striking display of wisdom and of power, exemplified in the singular adaptation of the structure of these animals to their peculiar habits. Thus how wonderfully is the Tiger formed: how extraordinary as well as wonderful, must be the organization of Serpents! Who (unless he had witnessed the fact) could have believed that the animal frame was capable of separating from its juices, and of retaining with impunity, a poison instantly fatal, not only to other animals, but to the animal itself, if again mingled with the juices from which it had been excreted!

Nor in all these things is the benevolence of the Deity less conspicuous than his wisdom. All must die; and death

from rapacious or venomous animals, is probably not in any degree more painful, than many other modes of death which we constantly witness. There is in truth, to our own narrow and selfish feelings, something exceedingly painful in the idea of being torn to pieces by a Tiger, or stung to death by a Rattlesnake; but how many thousands of mice are destroyed by cats? and how many myriads of flies are poisoned by spiders, every day we live? and yet we hardly commiserate them. The question therefore, is simply a question of degree; and viewing the existence and the destruction of animals as they ought to be viewed, on the great scale, we find that the whole is perfectly in unison. While as checks on over productiveness in temperate climates, we have cats and spiders; amidst the grandeur and the luxurious development of the Tropics, the same wise purpose is executed by the Tiger and by the Rattlesnake.

As we advance from the Equator into the temperate zone, the size of animals in general, like the size of vegetables, becomes gradually smaller. Like the vegetables too, the animals of the temperate zone are more gregarious than within the Tropics. Hence number, as among vegetables, compensates in some degree for diminished magnitude. The two kingdoms of nature therefore are beautifully analogous; for the gregarious grasses, which as we before observed, form so marked a feature in the vegetation of temperate climates, constitute in one shape or other the principal food of the gregarious tribes of animals. Thus the whole cattle tribe—The Ox, the Sheep, the Goat, the different varieties of Deer, the Rabbit and Hare, also the Horse and the Ass, with a multitude of other well-known animals of a similar character, are natives chiefly of temperate climates, and obtain their nourishment almost entirely from the grasses. Among birds, the numerous species of the Gallinaceous or Fowl tribe, may be said to derive their food from the same source. As regards the existence of animals therefore, the gramineous tribe of plants is more important than perhaps any other, and could not be annihilated without the destruction of the present order of living beings.

As further examples of animal species indigenous to temperate climates, may be mentioned the Canine species and

those allied to it, most of which are more or less carnivorous; also the Hog; and a variety of other animals that need not be here enumerated. The Hog tribe as is well known are omnivorous; but in their natural state they feed principally on the seeds and roots of plants. Among birds peculiar to temperate climates, are various tribes of Water-fowl subsisting on fish and on insects. Of the smaller land birds, the various Songsters offer a remarkable contrast to the birds of similar form within the Tropics; not only from their more melodious notes, but from the simple colouring of their feathers. In temperate countries the Insects are still exceedingly multiplied; though in general, like the other animals, they are much smaller in size than the Tropical insects; their forms, their colours, and other peculiarities, are also much less striking.

As we advance toward the Poles, the animals of temperate climates are observed gradually to decline in number. The vegetable feeders become reduced to a few hardy species, and at length in the remote north and south scarcely any vegetable feeders remain. So far as shrubby plants continue to grow in these inhospitable regions, individuals of the Squirrel tribe find subsistence on their seeds and roots. But the most singular herbivorous animal is the Reindeer, whose principal food is afforded by nature, in a species of moss peculiar to very cold countries. The animals nearer the Poles, are either carnivorous or piscivorous. The Arctic Fox and the Bear are familiar instances, as terminating the Zoological series, viewed in connexion with the influence of climate.

We have in the last place, to notice what is most remarkable in the distribution of Marine animals.

For the reasons before stated, the general temperature of the ocean differs considerably from the temperature of the neighbouring land. Owing to this difference of temperature, and to the peculiar mode of subsistence of marine animals, their food being obtained chiefly from the waters they inhabit; the distribution of these animals, particularly within the frigid zone, varies much as compared with the distribution of animals that are entirely terrestrial. It is true indeed, that in all climates, the denizens of peculiar localities, as fresh water species, and species whose resort

is the shallows on the coast, are influenced by the climate nearly as much as land animals; and within the Tropics, this influence extends in some degree even to the species dwelling in the wide ocean. But far to the north, and to the south, such species are influenced in a manner altogether different. Thus the largest of known animals the Whale, and of course those other animals which become its prey, roam through the utmost Polar seas; where on land the intensity of the cold would prevent the existence of any animal whatever. The whale is enabled to live in so rigorous a climate, solely in consequence of the greater warmth of the Polar ocean formerly explained. Among the larger inhabitants of the ocean in Tropical climates may be mentioned the Shark tribe, which in respect of ferocity and voraciousness may be classed with the tiger or any kindred species on land. The influence of climate on marine animals is further shown as we have said, by the enormous size of many of the Tropical shell-fish and mollusca. The colouring of these and also of other productions of the Equatorial seas, often exhibits so much lustre and beauty, as to rival the most splendid of the feathered race. In temperate climates, and from the equal temperature of the sea even within the frigid zone, various species of fish are, like terrestrial animals, much disposed to be gregarious. The shoals of Herring, Mackerel, and other well-known visitants of our coasts, are familiar examples of the gregarious tendency. The Salmon and the Sturgeon may be adduced as instances of fish inhabiting chiefly the rivers of temperate and colder countries. While in the same climates, instead of the magnificent Pearl Oyster of the Tropics, there appears our common Oyster, so diminutive and unsightly, yet so profitable to man.

We have thus seen that animals like plants have in general been adapted to particular climates. The numerous cold-blooded animals of the Tropics—even the warm-blooded Tiger itself, amid the Polar snows would instantly perish. The Arctic bear would be not less unable to live under the scorching rays of a vertical sun. Yet though adaptation to one climate be the general law regarding animals as well as plants, some species of animals have, as evidently as some species of plants, the faculty of accommodating themselves

to all climates. These species like the plants similarly endowed, are for the most part natives of temperate climates; the transition from such climates to either extreme, being much less violent than from one extreme to the other. Thus our domestic animals have been successively introduced into the New World at various periods since its discovery, and are now in incredible numbers, spread over the whole of that vast continent from Canada to Paraguay. The greatest increase has been of the Horse, the Ox, the Sheep, the Goat the Dog, the Cat, and the Hog. The Rat too, though an unwelcome intruder, has been not the least prolific. The different varieties of domestic Poultry have multiplied to an equal extent. Even Insects have been introduced and widely spread, as is well known to horticulturists.

Like plants, most animals also are readily domesticated, and thrive in climates similar to those of which they are natives. The most striking instance is the Rein-deer; so lately as in the year 1773 introduced into Iceland, and now exceedingly numerous in the interior of that country. From these powers of accommodation to climate, from the agency of man, and from accidental causes, the distribution of the larger animals over the globe has in comparatively recent times been very much modified. Nor is there any reason to believe that the distribution of these animals is yet stationary, but on the contrary, that their distribution will undergo still further changes.

Among the more remarkable habits of animals, may be noticed the migratory propensities of certain species. The migration of land animals is always much limited, and may be entirely prevented by natural obstacles; such as the asperities of the earth's surface, sands, deep rivers or other large accumulations of water. But many birds and even insects, possessing powerful locomotion and having their course through the air, may literally be said to follow the sun in their migratory progress. It is hardly necessary to state as examples, the birds of passage so well known as the Swallow and the Cuckoo. These birds during the summer months visit our northern climate, and feed on insects, whose multiplication would otherwise be boundless. Their office fulfilled here, on the declination of the sun they again retire to the south, and are succeeded by different birds from countries

still further north. Such are the Woodcock and others, which escape to our shores from the rigorous cold of a Polar winter. Nor is migration confined to the higher classes of animals. The wonderful powers of flight possessed by many insects, enable them to travel over an immense extent of country. The Locust and the Ant tribe are familiar examples. These insects occasionally migrate in countless swarms from the lands to which they are indigenous, and lay waste others far remote.

Equally remarkable is that habit of animals termed Hybernation. Like the plants of temperate climates, some animals have the faculty of passing the colder season of the year in a state of sleep. The Hedgehog and the Dormouse may be mentioned as examples of quadrupeds possessing this faculty. Additional instances might be given in all the classes of animals. Nearly allied to Hybernation is that peculiar instinct which guides many of the inferior animals to deposit their eggs in the earth, or in some other place of safety, that they may be preserved during the season of diminished temperature. This instinct is particularly observable in insects whose lives are ephemeral, or are at the utmost prolonged for a summer.

There is yet another circumstance that remains to be noticed, as being connected with the adaptation of animals to the climates in which they live; namely the Clothing or covering with which animals have been supplied by nature. Every one is acquainted with the general fact that wool, fur, eider-down, and similar articles, are obtained for the most part not from the copious source of every superfluous production, the countries within the tropics, but from the cold and comparatively unprolific regions of the temperate and of the frozen zones, where they have constituted the appropriate vesture of different animals. Perhaps in the whole range of creation, there is not any thing more calculated to excite our admiration. However we may view these means of guarding animals from being injured by the cold, whether as a part of that conservative faculty with which animals have been endowed and by which their existence is maintained, or as an immediate act of Providence, still the adaptations are so striking and obvious, as to render it impossible to doubt for a moment that they have all been

contrived for the purpose which is accomplished, and that they are the results of fore-knowledge and of design.

We have thus given a rapid sketch of the distribution of animals over the globe. In this sketch we have endeavoured to point out the wonderful adaptations of the several classes of animals to the circumstances in which they are placed, together with the beautiful symmetry and equilibrium exhibited in zoology, not less than in the arrangements of inanimate matter. Throughout we have intentionally and as far as was possible avoided those details, the consideration of which belongs to other departments. But it has been our aim to state such prominent facts, as appeared best calculated for the elucidation of our argument. In particular it has been our desire to show—how number among the weak is made to compensate for magnitude among the strong; how exuberance in one species is made to contribute to the existence of another; how ornament and boundless profusion characterize the countries within the tropics, while the temperate climates are not less distinguished by utility and capacity for change; how even in the rigorous and barren neighbourhood of the Poles, where life becomes a struggle for existence, animals have been expressly furnished with clothing suitable to these regions;—in short, we have endeavoured to explain, how every animal in every climate has its day, and by some peculiar contrivance has been enabled to maintain its rank in creation, and to assist in preserving the general equilibrium.

Hitherto we have considered the works of nature without reference to Man. For aught we can see to the contrary, they might all have existed, and every arrangement and operation might have been very nearly if not exactly the same as at present, though man had never been called into being. But still for a moment longer keeping man's existence out of view, let us as under a former division of this Treatise inquire, what would have been the use of all this elaborate design without an ulterior object? Would an intelligent Creator have made such a world, and have left it thus incomplete? It is evident that the other beings inhabiting this earth, live and die without in the slightest

degree comprehending the vast system of which they constitute a part. Hence they are merely unconscious agents, from which their Maker, while he has furnished them with the instincts necessary to their existence, and has awarded equal justice to all, has yet chosen to withhold the privilege of reason. That a Creator, as benevolent as he is wise, might for his own gratification have made such a world, and without any other inhabitants, is indeed possible. But even admiting that possibility, the probability surely is that he would not there have finally "rested from his labour." His benevolence would have prompted him to communicate to other beings, a portion of the gratification which he himself is supposed to derive from the contemplation of his works. In the beautiful world which he had created, He would have wished to see *one* being at least, capable of appreciating to a certain extent His design and His objects. Such is a plain inference deducible from the manifest attributes of the Creator; and what is the fact? Is not man such a being as we have supposed? Throughout the world, though perfectly independent of him, is there not a clear foretoken of his existence? Has he not been placed at the head of that world, so obviously prepared for him, and thus constituted "the Minister and Interpreter of nature?" Surely no one will be inclined to doubt that such is the position of man with reference to other animals. Equally undeniable is the striking accordance of these deductions from the view of external objects, with what is written of the origin of man by the sacred historian: "and God said, that it (the world which he had prepared) was good. And God said, let us make man in our own image, after our own likeness, (that is to say, endowed with reason and with the power of reflection). And let him have dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over every creeping thing, that creepeth on the earth."

We thus arrive at another and to us the final step in the great design of the Omnipotent: the creation and the faculties of Man.

§ 3.—*Of the present Position and future Prospects of Man.*

The consideration of the faculties of man, and of his

position in the world he inherits, belongs in all its details to another department. We advert to these subjects here, with the view only of completing our sketch of the physical relations of animated beings. The observations we have to offer will be comprised under two heads:—as to the means by which man has acquired and maintains the ascendancy he enjoys:—as to the conclusions to be drawn from man's elevated position, and from his superior intellectual character.

With regard to the means by which man has acquired and maintains his ascendancy, it may be observed that these means are quite peculiar, and far from being such as at first perhaps we might deem conducive to such an object; though when once known and understood, the beautiful design and harmony they evince immediately become apparent.

The supremacy of man has not been the result of his own personal strength, nor is it so upheld. On the contrary, many animals are larger and more powerful than he is; while few of his size are naturally so incapable of self-defence, or during so long a period suffer from the dependent helplessness of infancy and of old age. Neither is his frame superior in external adaptation to climate; for while nature has furnished other animals with clothing adapted to the temperature in which they live, man has been brought into being absolutely naked; and moreover remains so in every climate he inhabits, from the Equator to the Poles. Lastly, the pre-eminence of man has not been owing to his more extensive range of diet, or to his greater ability for assimilation; for though man be omnivorous in one sense of the term, he is not omnivorous according to the application of the term to other animals; that is to say, man does not eat indiscriminately of every kind of aliment in the state in which it is afforded by nature, for even in his rudest condition he adopts some process of cookery. How then has man gained the high station which he occupies? The answer is simply—by his Reason. Man has been created a reasonable being; and this endowment amply compensates him for the want of the animal requisites of strength—for deficiency of natural covering—and for his restricted ability in assimilating his food. By his reason he

is enabled to command the strength of the elephant; to choose from every production of nature whatever is adapted for his clothing, and thus to array himself according to his pleasure, or the exigencies of the climate in which he resides; to extract wholesome nourishment from the most unpromising, even from the most deleterious articles. There was no necessity therefore why man should himself be as unwieldy as an elephant, or be encumbered with any vesture that in some situations might be oppressive, or be able to digest without culinary preparation any coarse and intractable substances. Thus mere animal endowments not being requisite, the Creator's wisdom has been displayed in another manner and with a wider scope. In furtherance of His design, He has limited the bulk of the human species to that happy medium, combining strength with convenience; and to an organization delicate and sensitive in the highest degree, but nevertheless accommodating, He has superadded a form at once peculiar, appropriate, and beautiful!

When speaking of temperate climates, we remarked that they seemed to be characterized by the utility of their productions, and that the plants and animals of these climates generally possessed greater powers of accommodation than the plants and animals of either of the extreme climates. Now Man, by an express arrangement of his Maker, has apparently been constituted a native of temperate climates; and only in these climates can his powers be said to be completely developed. Within the tropics indeed, human existence is flourishing; for there the immediate bounty of Providence affords to man a copious and admirably adapted nutriment. Yet in the midst of that profusion, and without any adequate motive to call forth exertion, the reason of man too often languishes, while his animal tendencies predominate, and his life is spent in apathy and in sensual gratifications. On the other hand, under the cheerless sky of the frigid zone, imperfectly nourished by scanty and unsuitable food, the powers of his mind like those of his body are stunted, or are engaged solely in combating the rigours of his situation. But in the temperate parts of the earth, the evil consequences of both those extremes are avoided, while the beneficial influences

of climate remain. Urged by the stimulus of necessity, and at the same time having at his command the astonishing capability of nature, man is in temperate climates surrounded by motives of every kind, and his faculties thus attain their utmost development. As familiar examples of the effect of this expansion of the human reason, let us view man under the three aspects to which we have before alluded; namely with reference to his strength, his food, and his clothing inclusive of his habitation.

In the first place, with regard to his strength. The strength of man is not only that which is his own, almost infinitely magnified by ingenious mechanical devices of every kind and of every degree, up to the stupendous agency of steam; man has moreover subdued to his service many of the larger animals, while those he cannot so appropriate he destroys. As weapons, he wields every instrument offensive and defensive, from the rude but effective club or arrow, to the warlike engines to which he has applied the discovery of gunpowder. Whatever his wants require he obtains by tools; from the humble spade, to that perfection of machinery which almost rivals the operations of intelligence itself.

In the next place, view man with reference to his food; what wonders has not his reason enabled him to achieve among the fellow inhabitants of his own temperate climate! In the vegetable kingdom let us consider the astonishing mutations and increase of the cerealia or corn tribes, the transformation of the sour and forbidding Crab into the rich and fragrant Apple, of the harsh and astringent Sloe into the delicious Plum, of the coarse and bitter sea side Brassica into the nutritious and grateful Cauliflower, all which changes and numerous others of a like kind have been effected by man. Nor have the transformations which he has produced among animals been less wonderful than those among vegetables. All the numerous varieties of cattle, of sheep, of horses, of dogs, of poultry, and of all the other animals reared as food or for any purpose domesticated, have sprung from a few wild and unattractive species; and have been made what they are, in a great degree by his intervention. Moreover the most useful of these varieties of animals have been transported by man

into every region of the globe, to which he has himself been able to penetrate.

Lastly, in the clothing and habitations of man, the surpassing influence of his reason is equally conspicuous. For covering his naked body, a surface of considerable extent is necessary; larger indeed than is presented by any natural texture, unless perhaps by the skins of animals of great bulk, or by the leaves of some plants; which therefore in the rudest states of society, usually constitute his only dress. But by the art of weaving, he has been enabled to produce garments of any size, and from materials which would seem the least fitted for such conversion. Thus man can not only clothe himself in any manner, and according to the temperature of the climate in which he lives, but he can associate with the articles of his dress every species of ornament his fancy may dictate. His choice of materials for the construction of dwellings is not less extensive than for his clothing. As climate and other circumstances may require, he abides in the humble cabin, or in the splendid palace, in the temporary hut, or in the enduring castle formed to withstand alike the tempest of war and of the elements.

Such is man, and such are a few of those great changes in this world which under the guidance of his reason he has had the power to accomplish. And what a splendid evidence of design and of preconcerted arrangement on the part of the great Creator, is thus exhibited by viewing the inherent properties of matter and its various conditions, with reference to the works of man. Had water for instance not been constituted as it is, man could never have formed the steam engine. Had not the productions of the temperate climates been formed with that capability for change, by which they are so much distinguished, man could never have moulded them to his uses by altering their character. There was no reason why such properties should have been communicated; there was even no reason why the objects in which these properties exist, should have been created. But they have been so created; and what are we to infer? No one surely will now maintain that the objects of nature possessing these properties, have been the result of chance, or have been created without an end. They must

therefore have been created with design; and if with design—most obviously with design having reference to the being man, not yet in existence.

Thus far we have considered the state at which the earth has arrived, and man, an animal endowed with reason, placed as its chief inhabitant. But we may yet extend our view to the prospects in futurity.

We have seen that this earth has not suddenly emerged from chaos to its present condition; but that by a succession of violent and disruptive changes, it has been progressively brought into different conditions, and progressively tenanted by higher orders of beings. We the last of the series, in our own creation and in the faculties with which we have been endowed, behold the most striking exemplification of the wisdom and of the power of the Deity. But does the great design abruptly terminate here? Has this earth arrived at the ultimate stage of its existence? Have its inhabitants attained the utmost perfection of which they are capable? Are there not further convulsions, and still higher orders of beings in contemplation? The answers to these questions are known only to the great Author of the universe, and concern us not. There is one question however, connected with this subject, in which we are deeply and personally interested—What is to become of man? Is the being who surveying nature, recognises to a certain extent the great scheme of the universe, but who sees infinitely more which he does not comprehend, and which he ardently desires to know; is he to perish like a mere brute—all his knowledge useless, all his most earnest wishes ungratified? How are we to reconcile such a fate with the wisdom—the goodness—the impartial justice—so strikingly displayed throughout the world by its Creator? Is it consistent with any one of these attributes, thus to raise hopes in a dependent being, which are never to be realized? thus to lift as it were a corner of the veil—to show this being a glimpse of the splendour beyond—and after all, to annihilate him? With the character and attributes of the benevolent Author of the universe, as deduced from His works, such conceptions are absolutely incompatible. The question then recurs—What is to become of man? That he is mortal like other animals, sad experience teaches him; but does he like them,

die entirely? Is there no part of him, that surviving the general wreck, is reserved for a higher destiny? Can that within man which reasons like his immortal Creator—which sees and acknowledges His wisdom, and approves of His designs, be mortal like the rest? Is it probable, nay is it possible, that what can thus comprehend the operations of an immortal Agent, is not itself immortal?

Thus has reasoned man in all ages; and his desires and his feelings, his hopes and his fears, have all conspired with his reason, to strengthen the conviction that there is something within him which cannot die. That he is destined in short for a future state of existence, where his nature will be exalted, and his knowledge perfected; and where the great design of his Creator, commenced and left imperfect here, will be completed.

BOOK III.

FUNCTION OF DIGESTION:

COMPRISING A SKETCH OF THE

CHEMISTRY OF ORGANIZATION.

CH. I.—OF THE COMPOSITION AND NATURE OF ORGANIZED BODIES IN GENERAL; AS COMPARED WITH INORGANIC MATTERS.

HAVING in the foregoing pages given a summary view of the chemical properties of bodies not organized, and of the laws of their union; having also considered the general relations of inanimate matter and organized beings, on the great scale in which they are offered to us by nature, together with the present position and future prospects of man; we now proceed in the last place, to inquire more particularly into the nature of organization; and for this purpose shall give a short account of those chemical properties and laws of union, by which organized beings are distinguished from inorganized matters.

"A living being considered as an object of chemical research, is a laboratory within which a number of chemical operations are conducted; of these operations one chief object is to produce all those phenomena, which taken collectively are denominated Life; while another chief object is to develope gradually the corporeal machine or Laboratory itself, from its existence in the condition of an atom as it were, to its utmost state of perfection. From this point of utmost perfection, the whole begins to decline as gradually

as it had been developed; the operations are performed in a manner less and less perfect, till at length the being ceases to live, and the elements of which it is composed again set free, obey the general laws of inorganic nature."* Such is the history of organic existence; nor though the periods of developement and of decay be infinitely varied in different species, does a single individual remain for a moment stationary; but all sooner or later, transcend their prime and finally share the common lot of dissolution.

That peculiar principle or principles which under some condition or other exist in all organized beings, and by which they are distinguished from inanimate matter, have received various appellations. In the present inquiry these principles are viewed as agents; and to discriminate them from Heat, Electricity, and other agents operating on inorganic matters, they are denominated Organic Agents. The difficulty of our investigations into the nature of these principles or agents, will be much lessened by endeavouring previously to have a clear understanding of what these agents actually do, and of what they cannot do. We shall therefore treat of the subject of organized bodies under the two following heads:—Section I. Of Organized Bodies considered as Chemical Compounds; and Section II. Of the nature of Organic Agents.

§ 1.—*Of Organized Bodies considered as Chemical Compounds.*

In their decided forms, no two things perhaps can be conceived to offer a stronger contrast, than the two great divisions of organized bodies—vegetables and animals. Yet the forms of these two kinds of bodies so gradually approximate, and seem even to coalesce, that it is not possible to say where the one ends and the other begins. The same remark applies to the chemical composition of vegetables and animals. Vegetable substances in general, contain essentially no more than three constituent elements, Hydrogen, Carbon, and Oxygen; while animal substances usually involve a fourth, Azote. Yet there are many vegetable substances of whose composition azote forms a considerable

* Berzelius Traité de Chimie, tom. v. p. 1.

part; while certain animal substances are entirely devoid of azote. It is obvious therefore, that the mere chemical composition of a substanee, at least its eonsisting of three or four eonstituent elements, will not enable us to determine whether the substance be vegetable or animal; and that in many instances, when this point happens to be doubtful or unknown, we must have other data before we can form a conelusion.

Besides the four eonstituent elements of whieh all organized substances are varied compouuds, other ingredients generally enter into their eomposition. These other ingredients are in very minute quantity, and are not so essential to the existence of organized substances as the four eonstituent elements above named; yet however minute the quantity, the influence of these other ingredients seems to be very great; they are, Sulphur, Phosphorus, Chlorine, Fluorine, Iron, Potassium, Sodium, Calcium, Magnesium, and probably more besides. These ingredients have by most chemists been deemed extraneous, or foreign to organized bodies; but we shall presently show that there is good reason to believe that the office of such additioual ingredients, though different from that of the four constituent elements, is nevertheless most remarkable.

These four constituent elements of organized bodies, along with the additional ingredieuts, are iu the present state of our knowledge alike denominated, The Ultimate Elements of organized bodies; but for sake of distiuction, hydrogeu, carbon, oxygen, and azote, may be termed the Esseutial elements; aud sulphur, phosphorus, &c. the Iucideutal elements of such bodies.

The combiuations of ultimate elements with one another aeeordiug to certain laws, produce what are denominated the Immediate or Proximate Elements of organized bodies. Of such proximate elements, Sugar, Oil, Albumen, &e. are familiar examples.

We shall adhere to these distinctions in the following pages.

Perhaps it may be stated as a general law, that uo substance entering into the eomposition of a living plant or animal, is so puro as to be capable of assuming a regularly crystallized form. Justead therefore, of being defined by

straight lines and angles, almost all solid organized substances are more or less rounded, and their intimate structure is anything but crystallized. The composition of organized fluids is equally heterogeneous; and though the basis of nearly every one of such fluids is water, many of them contain a variety of other matters.

Organized substances may be arranged under two general classes;—*a*. Substances consisting of proximate elements, which though they do not crystallize while in the living plant or animal, can yet by various processes be so far separated from extraneous matters as to be obtained in a state of purity, and thus be made to assume the crystallized form; and *b*. Substances generally consisting of proximate elements, which cannot under any circumstances be made to crystallize.

For the sake of comparative illustration, we shall describe a few of the more remarkable crystallizable and uncrystallizable proximate elements of which plants and animals consist.

The proximate elements of plants, taken in the widest acceptation of the term, are probably as numerous as the plants themselves; so that any attempt to enumerate them here would be quite impracticable. A few of these proximate elements however, are so abundant and so generally present in vegetable productions, that they particularly claim our notice.

The peculiar proximate principles of plants we shall notice may be divided into three great classes:—1. Proximate vegetable elements arising from the combination of hydrogen and oxygen with carbon, in the same proportion that constitutes water: 2. Proximate vegetable elements in which oxygen predominates; and 3. Proximate vegetable elements in which hydrogen, or rather hydrogen and carbon predominate. Of these, the first class is the most important and will chiefly occupy our attention.

Besides these three great classes of proximate vegetable elements, there are others which contain azote: and some of these proximate elements containing azote will, from their intermediate nature between vegetable and animal matters, require particular description. Many of the other

proximate vegetable elements containing azote frequently exhibit weak alkaline powers. Such are the peculiar proximate elements of Opium and other narcotics; also of Cinchona; and a variety of others, chiefly employed in medicine.

1. Of the three great classes of proximate vegetable elements, the first as we have said requires our especial attention, from including the Saccharine and Amylaceous matters so extensively used as food by man and animals. Their chemical composition is distinguished by the proportion of the hydrogen and oxygen they contain, which is the same as in water. Of this class, the saccharine proximate elements strictly so called, generally crystallize; the amylaceous proximate elements never crystallize. As examples of the crystallizable proximate elements belonging to this class, we shall in the first place select the principal varieties of sugar.

a. Crystallizable proximate elements. Sugar.—Chemists are acquainted with several varieties of sugar derived from different sources. We shall however confine our attention to the three most important varieties, viz., cane sugar, the sugar of grapes and of fruits in general, and the sugar of milk.

Cane Sugar, the common sugar of commerce is chiefly produced by the well-known sugar-cane. It exists also in the beet and other roots, of which on that account large quantities are grown in France and other countries. An excellent sugar is also obtained for domestic use, from a species of maple common in North America.

The sugar of grapes constitutes the sweet principle of grapes, and probably of fruits in general. Grape sugar differs from cane sugar, in being less sweet and less soluble in water. It also crystallizes with difficulty, and its chemical relations are different from those of cane sugar. Cane sugar, as well as Starch and Lignin to be presently described, can be converted into the sugar of grapes; but we cannot invert the process, and convert the sugar of grapes into cane sugar.

The sugar of milk, as its name implies, exists in the milk of animals. It is much less sweet and soluble in water than

cane sugar; and in its chemical relations, is altogether different both from cane sugar and from the sugar of grapes.

These three varieties of sugar have been ascertained and are now generally admitted to consist of three essential constituent elements—hydrogen, oxygen, and carbon; in all these varieties the hydrogen and the oxygen having to each other exactly the proportion, in which they form water. It has been therefore with great probability inferred, that these two elements are really so associated in these varieties of sugar; consequently, that these sugars are all compounds of water and carbon, or in the language of Chemists. Hydrates of Carbon. We cannot however produce artificially either these sugars, or any other organized compound, by directly combining their elements; because we cannot bring the elements together, precisely in the requisite states and proportions. Still there is no doubt, that if the elements could be so brought together, the compounds thence resulting, would be the same as the natural compounds. For as we shall afterwards endeavour to show, organic agents do not change the properties of the elements, but simply combine them in modes which we cannot imitate.

Vinegar is another well known proximate element, which not only forms crystallized compounds readily with many other bodies, but in its most concentrated state is itself also crystallized. Now it is not less worthy of note than in the case of sugar, that vinegar altogether so different from sugar in its properties, is generally considered to be precisely analogous in its composition; that is to say, vinegar is a binary compound of carbon and water, but the proportions of carbon and water are different from the proportions that form sugar. There is however a characteristic distinction between these two substances, inasmuch as vinegar does not exist ready formed in vegetables but is always produced artificially; not indeed, any more than sugar, by directly associating its elements; but by the process of fermentation and by other means, this acid may be formed from sugar and from the allied substances to be presently mentioned. Yet we cannot work backwards, and by any artificial process again form sugar from vinegar; though organic agents seem

to possess this power, as we shall more particularly have occasion to notice.

The Lactic acid is another proximate element, consisting like sugar of carbon united with hydrogen and oxygen in the proportion in which they form water. The lactic acid differs altogether from vinegar in its properties: but like vinegar is usually obtained artificially not from cane sugar, but from the sugar of milk and from other sources. Many of the compounds of lactic acid readily crystallize.

b. Non-crystallizable proximate elements.—We now proceed to consider the composition of a totally different class of substances, which under no circumstances natural or artificial ever assume the crystallized form; and the structure of which in the common and strict sense of the term, may be said to be organized. The well known proximate elements, starch, lignin, and gum, are the chief of these non-crystallizable or organized substances of vegetable origin; on each of which we shall offer some brief remarks.

Starch.—The proximate element of plants denominated starch, is obtained in slightly modified states from a great variety of vegetables, but principally from the seeds of the Cerealia. Even by the unassisted eye, starch is seen to be composed of minute particles; which when examined with a microscope, are found to be granules more or less rounded, without any apparent trace of crystallization; but, on the contrary, having a distinctly organized structure. These granules are conceived to be moulded in the cells of the texture by which they are formed; for it would appear that the state of the granules when first secreted and deposited in the cells, is semifluid, and that the excess of water is subsequently removed. Raspail and Dumas have shown that each of these little grains is covered with a peculiar striated integument, not affected by water at the common temperatures; within which integument is enclosed a substance rather more soluble.* According to some chemists, this interior substance has an analogy with gum; but probably it is only a variety of amylaceous matter, or rather as some suppose, it is the true proximate amylaceous element; the

* The most recent and accurate researches tend to show that the grains of starch consist of one substance only, arranged in concentric layers.—G.

external integument being an organized membrane having an entirely different composition.

Berzelius affirms that starch when burnt, leaves about ·23 per cent. of residuum, consisting entirely of the phosphates. But when this residuum is abstracted and allowed for, the essential composition of starch is found to coincide very nearly with the essential composition of sugar; that is to say, starch is composed of carbon and water, and the proportions of these constituents are very nearly the same as in sugar.

Lignin or the woody fibre, though assuming a great variety of appearances in different plants and including very different incidental matters, nevertheless in all those plants in which it has yet been examined, is found to possess very nearly the same essential composition; Lignin consists of about equal weights of carbon and of water. Such at least is the composition of woods so very different as the Box and the Willow, the Oak and the Beech. Hence it is perhaps not unreasonable to suppose that every variety of Lignin has a similar composition. All woods when burnt, leave a greater or less quantity of incidental mineral residuum in the shape of ashes; the nature of which, as observed above, differs exceedingly in different sorts of wood.

Gum is another non-crystallizable proximate element of vegetables, best exemplified by the well-known Gum Arabic. Gums derived from different sources vary materially in their appearance and properties, though the essential composition of all the varieties of gum that have been examined appears to be similar; *i. e.* they consist of carbon united to hydrogen and oxygen in the same proportion as in water. Gum like starch and Lignin when burnt, leaves more or less mineral residuum.

2. The second class of proximate vegetable elements to be noticed are those in which oxygen predominates. This class like the saccharine is very numerous; and the characteristic property of the greater portion is acidity. When pure, they for the most part readily crystallize or form crystallized compounds. The citric or lemon acid, the malic or apple acid, and the oxalic or sorrel acid, are familiar examples.

3. The third class of proximate elements includes those in which the hydrogen and carbon predominate over the oxygen, and is common both in vegetables and animals. Such proximate elements have usually an oily or fatty character. Oleaginous bodies are subdivided into fixed and volatile oils, and occur in an infinite variety of forms, some being fluid, others solid; yet in every instance, their peculiar oleaginous properties are so strongly marked that we seldom hesitate about their nature. In this distinctness of outward appearance oily substances are strongly contrasted with the class of saccharine substances, many of which have few apparent and sensible properties in common.

As an instance of a fixed oleaginous vegetable substance, we may mention olive oil. Olive oil as is well known, becomes partially solid at low temperatures—a property illustrative of the composition of oleaginous matters in general. The portion of olive oil solidified by cold readily crystallizes and is denominated margarine,* while the portion of the oil unaffected by the cold is termed oleine. In ordinary fats as mutton suet, a third proximate principle usually exists, to which has been applied the name of Stearine, from its solid condition at common temperatures. Stearine, margarine, and oleine exist in different fixed oils in very different proportions. In those natural fixed oils which retain their fluid state at common temperatures, oleine is usually the chief component; while in oleaginous matters exhibiting the solid form under similar temperatures, stearine and margarine are the most abundant elements. Train oil, hogs' lard, suet, &c., are instances of fixed animal oils, having these opposite characters.

Volatile oleaginous substances are usually remarkable for their strong odour. Many of these odours are among the most agreeable we experience, as the odours of flowers; others are equally the reverse. Volatile oils liked fixed oils are found of every degree of consistence between liquid and solid, and many of them like fixed oils are also easily separable by cold into a fluid and a solid portion. The volatile oils approximate to resins in their character, and

* Or as some suppose, the solidified portion is a chemical compound of margarine and oleine.

some of them on exposure to the air gradually become resinous.

Many oleaginous bodies both fixed and volatile appear to consist of certain compounds of carbon and hydrogen, and particularly of olefiant gas united with water in various proportions. Some volatile oils as the oil of turpentine, do not contain oxygen. Oleaginous bodies in general as they exist in living plants and animals, do not crystallize. But as we have said, they may by purification and analysis, be readily separated into their crystallizable components.

The proximate elements from animals, like those from vegetables, are very numerous. Proximate elements however differ from the three classes of proximate elements before described :—first, in containing a fourth constituent, azote; and secondly, in being usually all in the highest sense of the term organized, and incapable under any circumstances of assuming the crystallized condition.

The four principal proximate animal elements claiming our especial notice may be considered as modifications of one only, which may be termed the albuminous element. They are gelatine, albumen, (properly so called,) fibrine, and caseine; of these four proximate animal elements, caseine is distinguished from the others by being a product of secretion.* These proximate elements though retaining their essential characters, are subject to endless minor variations according to the organized structures by which they are produced. Most vegetables contain in small quantities proximate elements to be presently noticed, nearly allied to albumen, fibrine, and caseine.

Gelatine and Albumen.—When any part of an animal body, (with the exception perhaps of matters entirely oleaginous,) is boiled in water, what is so boiled is separated into two portions,—one portion soluble in water and forming with the water a tremulous jelly, or gelatine,—the other portion remaining insoluble, indeed becoming harder the longer it is boiled, and termed albumen.

Gelatine and albumen exist in very different proportions in the different textures; some of these textures as the skin being almost entirely convertible into gelatine, while

* The white of egg, which may be regarded as the typical form of albumen, is also a product of secretion.—G.

other textures yield comparatively little gelatine, and consist principally of albumen. In no animal compound does gelatine exist as a fluid; hence gelatine has been supposed to be produced by boiling, but the supposition does not appear to be well founded. Gelatine may be considered as the least perfect kind of albuminous matter existing in animal bodies; intermediate as it were, between the saccharine element of plants and thoroughly developed albumen; indeed gelatine may be said to be the counterpart of the saccharine element.

A familiar and characteristic instance of albumen, from which indeed the name is taken, is the *albumen ovi*, or white of egg. Albumen exists also in the liquid state as a component of the blood. Albumen is distinguished by the well-known property of becoming coagulated or solid by heat; and in such coagulated or solid condition, this proximate element as has been already stated, forms a large part of the fabric of animals.

Fibrine is found in the blood and muscles of animals, of which it constitutes the chief ingredient.

Caseine or the curd of milk is another modification of the albuminous principle. Caseine is found in the milk of animals, of which it may be said to be the peculiar characteristic. In recent milk caseine exists in a state of perfect solution, and unlike albumen will admit of the boiling temperature without becoming solid or coagulating. A very minute quantity however of almost any acid as is well known, will separate the caseine from milk in the solid form.*

* An attempt has been recently made to show that albumen, fibrin, and caseine contain a certain common fundamental proximate element, to which the name of Proteine has been given. That such a common proximate element may be derived from albumen, fibrine, and caseine, is not denied. Viewed indeed in connexion with organization and life, the supposition that some common proximate element adapted for ulterior changes exists in animal bodies is very probable, and accords well with the simplicity of natural operations. But that a substance obtained like proteine by the rude and disorganizing processes of common chemistry should be that common proximate element, or that such a substance should ever be employed at all in vital operations without undergoing the preliminary assimilating processes, is more than at present we are disposed to admit.

We have reserved for this place, where more likely to be understood, a few remarks on certain proximate elements to which we have before alluded as existing in vegetables, and which from their close analogy with the animal albuminous elements, constitute a sort of connecting link between vegetables and animals.

Vegetable Albumen.—The juices obtained by pressure from the leaves of almost all plants, when purified and exposed to the boiling temperature yield in greater or less proportion a flocculent deposit which when collected and dried, is found to have a composition and properties almost identical with the composition and properties of coagulated albumen from animals.

Vegetable Fibrine. When wheaten flour previously formed into a paste, is exposed to the action of a jet of water so as to remove entirely the farinaceous matter, a tough tenacious substance remains which was formerly termed gluten. According to recent researches, this glutinous substance is divisible into two portions, one of them having a composition and properties closely analogous to animal fibrine, and hence the term vegetable fibrine by which it is now usually designated by chemists. The term gliadine has been given to the remaining portion, which is peculiar to wheat. Vegetable fibrine is found in the seeds of all the cerealia, as well as in many other seeds and vegetable productions; but the seeds of wheat, of which it constitutes nearly ten per cent., far surpass all other vegetable substances in the proportion of vegetable fibrine they contain, and hence the superiority of wheaten bread as an aliment?

Vegetable Caseine. Peas, beans, and the seeds of other leguminous plants, also almonds, nuts, &c., besides small portions of vegetable albumen and fibrine, contain also a principle strongly resembling animal caseine both in composition and properties. To this vegetable caseine such seeds doubtless partly owe their characteristic property of forming milky compounds or emulsions with water.*

We mentioned that besides the four constituent primary elements of which vegetable and animal products consist, all organized proximate elements contain likewise certain

* See on the composition of the two last substances any of the recent works upon Chemistry.—G.

minute portions of other primary elements, which for distinction we termed incidental elements. These incidental elements of organized proximate elements now claim our attention.

The incidental inorganic elements found in plants and animals were formerly much disregarded by chemists. Many years ago however, circumstances drew our attention to the subject, and we became satisfied that so far from being unimportant, the presence of these incidental inorganic elements was actually necessary to the existence and developement of plants and animals. Later observations have confirmed the accuracy of this opinion; and for some time past, (indeed even to the present time,) the subject has occupied much of the attention of physiologists. The nature of this treatise precludes details, but a few examples for illustration may not be deemed irrelevant.

It seems to be satisfactorily ascertained that in plants and animals, primary inorganic elements exist in at least two conditions:—First, alkaline and alkaline earthy bases are associated with certain acid proximate elements peculiar to plants and animals. Secondly, incidental primary inorganic elements are associated or incorporated with the essential primary elements of which vegetables and animals are composed, in modes at present unknown.

An instance of the first mode of association of inorganic elements in plants and animals, is the potash in the juice of grapes; which in association with the proximate vegetable acid, the tartaric acid, forms the well-known cream of tartar, encrusting wine casks. In many plants, potash, lime, &c., are associated with the malic, oxalic, and other proximate acid elements of vegetables; and it is remarkable that in the same plants, and sometimes even in all the individuals belonging to the same natural family of plants, the same or similar saline compounds are met with, thus forming a characteristic feature in the composition of the plant, and at the same time showing the necessity of their presence in its economy. Among animal substances presenting an association of inorganic elements, we may mention the soda found in connexion with certain proximate elements of the bile, and imparting to that fluid its well-known soapy character.

The second mode of existence of inorganic primary elements in plants and animals, is shown in the minute residue left after their combustion, and constituting the ashes of plants and animals. The ashes of plants and animals of course include the alkaline and earthy bases, associated with their proximate acids, when such are present; but those incidental primary elements, to which we here more especially allude, usually consist of various earthy compounds in very minute proportion as compared with the entire bulk of the organized product. The most frequent of such compounds are the phosphates of magnesia and of lime, and alkaline and earthy sulphates, either alone or mixed with the carbonates of potash and soda, silex, the oxide of iron, &c. To some of these compounds we shall have occasion to revert in subsequent chapters. In the mean time we may observe that between these two well-marked varieties of incidental primary elements in plants and animals, there are innumerable intermediate grades, so that the two varieties may be probably considered as gradually running into each other.

For the sake of clearness, we have drawn out an abstract of the composition of some of the proximate organic elements, which will be found in TABLE III. in the APPENDIX; to this abstract the reader's attention is directed before perusal of the following observations.*

A cursory inspection of this table shows us how nearly crystallizable and non-crystallizable proximate vegetable elements agree in their composition; also that the apparent differences arise solely from the variable proportions of water contained in each, the proportion of carbon being supposed to remain the same, and from the presence in the non-crystallizable or organized proximate elements of minute quantities of mineral incidental primary elements. Thus grape sugar differs from cane sugar by containing less

* To avoid controversy, we have given the most recent analytic results with which we are acquainted. As approximate results they serve to illustrate the objects we have in view; though we much doubt whether any one of these analyses can be considered as representing the true composition of an organized proximate element. See Fownes, Manual of Elementary Chemistry, page 359.

water, the proportion of carbon being in both alike; while starch differs from cane sugar, by containing also less water, but in addition about ·23 per cent. of the earthy phosphates. Gum differs from milk sugar like starch from cane sugar, by containing less water, and by the presence of certain incidental mineral matters in small proportion. Vinegar appears to have no corresponding principle among non-crystallizable proximate elements; but in lactic acid and in lignin or the woody fibre, the proportions of carbon and water are absolutely identical, and the great contrast in the properties of the two proximate elements must depend on the modes in which the primary constituent elements are associated, and on the minute proportions of incidental mineral primary elements always existing in every variety of wood.

We have drawn the attention of the reader to these facts in order to facilitate the following inquiries naturally suggested by them:—First. As to the general modes in which the primary elements are associated in vegetable and animal proximate elements, and the influence of water more especially in modifying all organized proximate elements; secondly. As to the influence of incidental mineral elements in modifying organized proximate elements; and, thirdly. As to the changes which cannot be effected by organic agency, and the general modes by which organic processes are accomplished.

First. With regard to the modes in which primary elements are associated in organized proximate elements, the reader will remember our former general proposition—that as chemical forces are only two polar forces, the immediate composition of all chemical compounds must be binary. With inorganized compounds this we believe is generally admitted; but organized proximate elements have been usually supposed to be formed on different principles; in other words, the constituent molecules of organized proximate elements have been considered to be real ternary and quaternary aggregates, in which the chemical forces of the three or four primary elements of which they consist mutually balance each other, without regard to binary arrangement. We cannot accede to this opinion. Three or four, or, indeed, any number of masses in motion may be conceived to form a system, and to revolve round a common

centre of gravity. But such an arrangement has no analogy with the statical constitution of a proximate organized molecule, the primary constituent molecules of which are at rest. Controversy on the point however would be out of place here; and we shall simply state that view which we have long entertained, and which we conceive to be nearest the truth.

In treating of the forces of Homogeneity in the first part of this volume, we entered on the subject rather more fully than usual; because we thought the influence of those forces by which similar molecules of matter are associated and separated, were much underrated. But if they have been underrated in inorganic chemistry, they are much more underrated in the chemistry of organization; where the forces of Homogeneity appear to exert an influence little short of the forces of Heterogeneity. This predominance of the forces of Homogeneity in organized products doubtless arises from the peculiar properties of the primary constituent elements of such organized proximate elements, in which primary constituent elements the forces of Homogeneity are very remarkable. Thus instead of $\dot{6}$, the assumed weight of the primary molecule of carbon, in most proximate compounds of vegetable and animal origin the weight of the molecule (or rather super-molecule) of carbon is 12, 18, 24, &c., that is two, three, four, &c., of the primary molecules of carbon are associated together by the forces of Homogeneity into groups or super-molecules having such atomic weights. The same is true not only of the other primary elements of organized molecules, but of water and of various compounds of primary elements, as we shall have occasion to notice presently. Now it is a generally admitted fact, that the higher the atomic or combining weight of a molecule, whether that molecule be a primary or a super-molecule, the weaker are its chemical relations. In the super-molecules of carbon and of the other primary elements entering into the composition of organized proximate elements, the forces of Homogeneity must therefore often surpass in intensity the forces of Heterogeneity. But the forces of Homogeneity diminish in intensity, and probably like the forces of Heterogeneity, at length become evanes-

cent as the weight of the super-molecule increases; and hence one source of the comparative instability of all organized compounds.*

To illustrate the forces of Homogeneity, we shall make a few observations on the crystallizable substances whose composition is given in Table III.

Water enters into the composition of most organized bodies in two separate forms, which forms must be clearly distinguished and borne in mind by the reader. Water may constitute an essential element of a substance, as of sugar in its dryest states: in which case water cannot be disunited from the other elements, without destroying the compound: or water may constitute a complementary ingredient of a substance, as of vinegar in its crystallized state; in which case more or less of the water may frequently be removed without destroying the peculiar properties of the compound. Now a very large number of organized bodies (perhaps all those to which our present inquiry relates) contain water in both these forms; both as an essential element, and as a complementary ingredient; and in most instances, it is impossible to discriminate between the water which is essential, and that which is complementary. The mode however in which water is associated with the other elements of bodies, in these two states of combination, must be altogether different. Wherein the difference consists is imperfectly known; but from the explanation we shall now offer, the reader will more fully understand the nature of these two modes of union: perhaps some light may even be thrown on the causes of their difference.

Sugar from the cane in its purest state and when as free as possible from adhering water, is according to the present language of chemists, composed of 24 atoms of carbon and 22 atoms of water. Now we suppose these 24 atoms of carbon and 22 atoms of water to be associated into two super-molecules, weighing (24×6) 144 and (22×9) 198 respectively. So that we conceive a molecule of sugar from

* If the assumption be admitted that chemical forces are exerted only at the poles of molecules, while homogeneous forces are exerted over their whole superficies, we may urge an obvious reason for the predominance of the forces of homogeneity in certain molecules.

the cane to be a binary compound of a supermolecule of carbon weighing 144, and a supermolecule of water weighing 198. A similar statement may be given of the composition of milk sugar, another of the saccharine class of bodies. Milk sugar appears to consist essentially of an equal number of atoms of carbon and water, and may be said to be composed of 24 atoms of carbon, and 24 atoms of water; or, according to our views, of two supermolecules weighing (24 × 6) 144 and (24 × 9) 216 respectively. Again grape sugar, identical with the sugar of honey and of fruits in general, according to the present language of chemists is composed of 24 atoms of carbon, and 28 atoms of water; or according to our view of molecular arrangement, grape sugar is composed of two supermolecules, one of them, carbon weighing 144, as in the sugar of the cane—the other water, weighing no less than (28 × 9) 252. Hence the composition of these different varieties of sugar may be represented in the following manner :—

CARBON.		WATER.	
144	+	198	Cane sugar.
144	+	216	Milk sugar.
144	+	252	Grape sugar.

This molecular constitution of the saccharine bodies may be compared with the molecular constitution of acetic acid or Vinegar.

According to the present language of chemists, acetic acid in its purest and most detached form, is composed of 4 atoms of carbon, and 3 atoms of water; or according to our views, of two supermolecules weighing (4 × 6) 24 and (3 × 9) 27 respectively; while crystallized vinegar contains the same proportion of carbon with one-third more of complementary water. Thus the molecular constitution of these two different forms of vinegar may be represented as follows;—

CARBON.		WATER.	
24	+	27	Absolute acetic acid.
24	+	36	Crystallized or solid acetic acid.

We have stated the composition of acetic acid, in order to draw the attention of the reader to the difference between

the supermolecule of the carbon in that acid, and the supermolecule of the carbon in saccharine bodies ; a difference to which these two classes of bodies probably owe the striking differences in their sensible properties. But why the supermolecule of carbon should be 144 in saccharine bodies, and why this supermolecule should in general exist in the self-attractive form and produce sweetness ; or why the supermolecule of carbon in acetic acid should be 24, and why this supermolecule should have such a tendency as it exhibits to assume the self-repulsive form, and to produce sourness, we do not know and probably shall never be able fully to explain. Still there can be little doubt that a careful and philosophical examination of the phenomena, would go far to dispel the obscurity in which the subject is now involved.

Such are the principles which we conceive to regulate the chemical union of organized, and indeed as we have said, of all other compounds ; and if chemical union be so regulated, the inferences deducible from such modes of union are most curious and important. With these in general we have at present no concern, but the inferences more particularly relating to organized proximate elements are the following :—

1. We would draw the attention of the reader to the contrast between the two supermolecules of carbon and of water, constituting the different varieties of sugar; the supermolecule of carbon being uniform throughout the whole saccharine class, while the supermolecule of water is that which is variable.* Now there is reason to believe that this contrast holds in other instances ; that in different organized proximate elements of the same kind, the supermolecule of carbon or of some of its compounds, remains the permanent and characteristic element ; and that the different modifications of the proximate elements are produced by

* In the former editions of this work, published so long ago as 1834, the composition of saccharine bodies was stated on the same principles as they are now given in Table III., i. e. the proportion of carbon was supposed to be constant, while the proportion of water only varied. At that time we believe such views of the composition of saccharine and other organized compounds were peculiar to the writer of this Treatise. We are glad to see they have now been adopted by others.

variations in the supermolecule of water, which may be called the modifying supermolecule.

2. The manner of the operation of the modifying agency may be thus explained. If to a portion of cane sugar we add that quantity of water, which by an easy calculation we learn is necessary to be united with cane sugar in order to its conversion into milk or grape sugar, we find that we cannot succeed in producing such conversion; and that the excess of water which had been added, flies off and leaves the cane sugar in its original state. On the other hand if we apply heat to milk or grape sugar, though we may indeed drive off part of the water essentially associated with these varieties of sugar, we do not obtain sugar similar to cane sugar, but we destroy or altogether decompose the milk or grape sugar. These facts therefore, show that the excess of water constituting the difference of the milk and grape sugars from the sugar of the cane, is really in some state of essential union, incapable of being imitated; while, in the cane sugar, the water may exist as an accidental ingredient only. In truth, according to our views of molecular arrangement, every individual supermolecule of water in the weaker sugar contains a portion of this excess of water, as an essential element of its composition. Hence such water cannot be separated from any compound, without destroying the entire crasis or constitution of its molecular arrangement; which as in the cases of grape and milk sugars, we find by experiment to be the result. On the other hand, we suppose that the molecules of complementary water form no essential constituent of the molecules of crystallized vinegar or of other bodies; but that these complementary molecules of water exist as a supermolecule in a state of chemical association with the supermolecules of which vinegar or other organized proximate elements consist, and hence the ease with which complementary water may be separated without destroying such proximate elements.

3. It may be advanced as a general rule, that the larger the number representing the weight of the supermolecule of any organized proximate element, whether such number represent the characteristic or the modifying supermolecule, the more easily may that proximate element be decomposed.

In like manner, when water is the modifying element of any compound, as it is in most organic compounds, the larger the number representing the supermolecule of the water, the greater for the most part is the solubility of the compound.

4. There are at present no chemical terms corresponding to those differences of composition, which we have brought under the notice of the reader. Now the terms strong and weak, which in commerce distinguish the different varieties of sugar, are sufficiently expressive: we shall therefore make choice of them in future, to denote the similar varieties of other organized compounds. Thus when we speak of a strong organized compound, we mean that its constituent supermolecules are, like those of strong cane sugar, less complicated than the supermolecules of a weak organized compound, like those of grape sugar. Again there are no terms expressive of the conversion of a strong into a weak organized compound, or the contrary. To express such conversion we shall adopt the terms reduction, and completion.

In the above illustrations of the modifying influence of water, we have selected sugar as our example, solely from its being the most familiar. But as we have more than once noticed, exactly the same laws appear to regulate the composition of every substance produced by organization. Thus in the strong fixed and solid oils or fats, the characteristic supermolecule of which as we have already said, has usually some relation to olefiant gas, the modifying molecule of water is very small, perhaps in some oily substances, is even a submolecule. Whereas in alcohol, which may be viewed as one of the weakest conditions of the oleaginous class, the weight of the modifying supermolecule of water is more than half that of the olefiant gas, and alcohol is perfectly soluble in water.

Gelatinous and albuminous substances also exhibit precisely the same variations. The strong tenacious glue employed in the arts, is made from the firmer parts of the hides of old animals; while the gelatinous size, or weak glue, is made from the skins of younger and more delicate animals. These two varieties of glue differ from one another, in the weights of the modifying supermolecules of water which

enter into their composition. In general it may be observed, that the substances composing the frame of old and of young animals, differ chiefly in the weights of their modifying supermolecules of water; and that the dissimilarity of their properties, is chiefly owing to this difference.

If the reader has clearly apprehended and will bear in mind the laws which have now been stated, as regulating the chemical constitution of organized proximate principles and the manner in which all organic substances are influenced by their modifying constituent, water, he will be able to accompany us in the observations we shall hereafter offer on the chemical operations of the stomach, and other processes of assimilation.

Secondly. We proceed to examine the influence of incidental mineral elements in modifying organized proximate substances.

We have more than once alluded to the circumstance, that the incidental matters existing in organized bodies were formerly considered as foreign, but that we never acceded to that opinion. We may now add, that the peculiar properties of organized proximate substances, as well as differences at first view so mysterious observed among bodies of the same essential composition, appear to us to be chiefly owing to their incidental ingredients.

We of course, are ignorant of the exact conditions in which the incidental primary elements exist in organized products, as well as of their mode of operation; but we can form plausible conjectures on both these points.

With regard to the conditions, there is little doubt that incidental elements always exist in organized products in their most energetic and elementary forms; that the lime and the oxide of iron for instance, found in the ashes of vegetable and animal substances existed in the original substance as calcium and iron, &c. Nay, there is every reason to believe that in some instances, not only the molecules of compound bodies as of water, but also the molecules of bodies considered at present as elementary, are divided into submolecules, and in this condition of submolecule constitute the incidental ingredient.

With respect to the modes of operation of incidental

elements in organized products, we can imagine them to be interposed among the constituent molecules of organized matter in a state of strong self-repulsion. This opinion is founded chiefly on the equal diffusion of these incidental primary elements throughout the organized substances in which they are found, and on the consequent great distance of the molecules of such primary elements from each other, which perhaps can hardly be otherwise explained. If these incidental ingredients were detached, or merely in a state of mixture with the constituent elements, as is implied in the notion of their being foreign, they would probably retain their self-attractive powers; and instead of being equally diffused among the constituent elements, they would be collected together into a mass or crystal, an arrangement never observed. For though crystallized bodies are found not unfrequently within organized substances, yet these bodies are always extraneous, and do not form any part of the living structure, of which, the primary elements under our consideration do actually appear to be integrants.

In further corroboration of the opinion now adduced, as well as of the supposed activity of incidental primary elements in organized products, we may direct the attention of the reader to the beautiful experiments of Sir John Herschel, who has shown that an enormous power (not less than 50,000 times the power of gravity!) is instantaneously generated by the simple agency of common matters submitted to galvanic influence; as, for example, by the agency of mercury alloyed with a millionth part of its weight of Sodium.* This most unexpected fact places beyond all doubt the efficiency of minute quantities of matter in producing the most extraordinary change of the polarities of larger quantities, and at the same time appears to throw no small light on many natural operations.

For instance, on the authority of this fact there is nothing improbable in the supposition that each molecule of an incidental primary element, interposed among the constituent elements of an organized substance, may become the centre of physical forces of such intensity as to influence,

* See Philos. Trans. 1824, p. 162. The process here indicated must be accompanied by magnetic (*i.e.* according to our view of Homogeneous phenomena).

and even subvert, the ordinary molecular forces of the constituent elements, and (under the control and direction of an intelligent organic agent) to cause such constituent elements to assume the organized condition. We may even perhaps go a step further, and conjecture the mode in which organization is effected. The earliest condition of an organized molecule is now generally admitted to be a minute cell, containing an energetic point termed its nucleus, which nucleus appears to be the germ or generator of the cell. Now the nucleus of a cell may be supposed to contain an incidental primary molecule in a state of activity, *i.e.* exerting a little sphere of force; and on and by the aid of this minute spheroidal force, there is no great difficulty in conceiving how an intelligent organic agent may out of the surrounding constituent molecules mould a cell.

Again the peculiar circumstances attending the fermentation and rapid spontaneous decay of organized products seem to owe their origin chiefly to the forces exerted by the incidental molecules they contain. Life extinct, the uncontrolled forces exerted by the incidental primary elements, may be supposed to contribute as much to the destruction, as when properly controlled and directed they have appeared to contribute to the formation of an organized mass.

Finally the subtle matters of contagion and miasmata, various medicinal substances whose effects are most astonishing even in the smallest doses; the still more recondite matters of heat and of light, with many others, all probably act on similar principles. At least the results of the operation of these matters cannot be explained by their mere quantity; which in the ordinary chemical acceptation of the term, is altogether incommensurate with the evident and striking changes constantly arising in the processes of nature from such agency.

The observations which have now been offered, are intended to apply to all the material elements entering into the composition of a living organized being. For no one element when assimilated to a living body, appears to be in its natural state, or to be capable of exerting precisely those powers which it is known to exert, when acting in virtue of its original inorganic properties. In short we may

thus recapitulate what has been said: besides the essential molecules constituting the ground-work of a living organized being, and which probably exert on each other to a certain extent the ordinary chemical influences of matter, it would seem that there are at the same time diffused throughout the whole living mass in exceedingly minute proportion, various other matters, the molecules of which appear to be in a condition of intense activity and self-repulsion. By these incidental ingredients, it would farther seem that the ordinary chemical properties of the essential elements of the organized living structure are variously modified; in particular that the essential elements are hindered from assuming a regularly crystallized form. Moreover these incidental matters entering into the composition of a living body, apparently furnish to the organic agent new powers utterly beyond our comprehension; which powers the organic agent has been endowed with the ability to control and direct, in whatever manner from the exigencies of the living organized being, may become requisite.

Thirdly. We have to consider those changes which cannot be effected by organic agency, and to make a few remarks on the modes by which organic processes are accomplished.

1. With regard to what cannot be effected by organic agency, we may observe in the first place that no organic agent has the power either of creating material elements, or of changing one such element into another.

By element it may be right to premise is here meant a principle which is not made up of others, and which consequently possesses an absolute and independent existence. Whether one or more such elements exist, it is not now our object to inquire. The astonishing discoveries of modern chemistry have shown that many of those substances formerly considered as elements, are in fact compounds; and as the science of chemistry is still progressive, it is probable that with the enlargement of its boundaries, there will be a still further diminution of the number of those substances which are as yet held to be simple. Admitting however for the sake of argument, that elementary principles do exist of such immutable character as has been supposed, from the

nature of organized beings, at least of all animals, it is impossible to conceive that any organized being possesses the power either of creating or of altering these elementary principles. No organized being has an independent existence, all animals derive their support from previous organization, which might be otherwise did they possess a creating power; nor can animals be nourished by any substances indiscriminately, as they ought to be were they possessed of a transmuting power. Yet while it is thus denied that organized beings possess the power either to create or to change in the strict acceptation of these terms, it has been admitted to be exceedingly probable that the organic agent is within certain limits, qualified to compose and decompose many substances which are now viewed as elements; and that the organic agent does thus apparently form and transmute these imagined elements. But to enter further in this place on the elucidation of these obscurities would be foreign to our present purpose.

2. The organic agent has not the power of combining elements in such a manner that the properties of the resulting compound shall differ from the properties of a compound formed from the same elements similarly combined by any other agent. The Deity has chosen to prescribe limits to His power, and to establish certain laws, to which He at all times rigidly adheres; and again adopting the language of Paley, "when a particular purpose is to be effected, it is not by making a new law, nor by the suspension of the old ones, nor by making them wind, and bend, and yield to the occasion; but it is by the interposition of an apparatus corresponding with those laws, and suited to the exigency which results from them, that the purpose is at length attained." In the instance before us, the attainment of the particular purpose of organic life is effected, not by any departure from the great scheme, but by new and different combinations. To suppose therefore that the organic agent can for example, combine oxygen and hydrogen in exactly the same proportion and in the samo manner in which they are combined when they exist as water, and from these elements so combined, can yet produce something different from water, is contrary to all reason, and would be in truth,

to accuse the Deity of subverting and of acting in opposition to his own laws.

We have dwelt the more strongly on these points, because among physiologists a vague notion seems to have prevailed, that organic agents have the power not only of changing the inherent and peculiar properties of bodies, but likewise of causing the results of their combination to be altogether different from the results which are produced under exactly similar circumstances by inorganic agency. If however the arguments we have advanced be well founded, this notion must be erroneous; and its erroneous character will be rendered still more evident by the observations we shall next offer, regarding the principles on which the operations within living organized bodies are really conducted.

3. The means by which organic agents accomplish the purposes for which they are designed, may be naturally divided into two kinds; those means which are dependent on peculiarity of composition and of structure, and those means by which this peculiarity of composition and of structure is produced.

Inquiry into the first of these means of action has already been in a great degree anticipated. A brief recital, therefore, is all that is here necessary. We have seen that organized substances are composed of the same elements, which exist abundantly throughout the world in the inorganized state; moreover, that these elements are subject to all the influences and agencies of inorganic matter. We have seen that organic agents are enabled to form certain proximate elements by variously combining the primary elements of matter; which proximate elements even when in the condition of crystals, it is not possible to imitate artificially. We have at the same time seen that these proximate elements, though they may have a natural tendency to crystallize, are as they usually exist in living bodies, prevented from crystallization, by having minute quantities of various primary elements diffused throughout their mass; the molecules of which primary elements are in some unknown state of activity, such perhaps as cannot naturally exist in the universe except when conjoined with organization. Further we have shown that the differences and

peculiarities of these minute elementary ingredients, are probably adequate for explaining the differences and peculiarities of the sensible and chemical properties of the substances which are formed by organization.

Having thus pointed out the general differences of composition existing among organized bodies, it remains to state that such differences of composition almost invariably indicate differences of structure. For though similarity of composition does not necessarily imply similarity of structure, yet similarity of structure perhaps without exception, indicates similarity or at least analogy of composition, and consequently similarity of action. Thus the woody fibre of plants is always formed of the substance termed *Lignin*, and never of resin or of albumen. The relation of structure to chemical composition is not less striking in the muscular fibres of animals, and indeed in all organic compounds of a definite character; the essential composition of such substances, though exhibiting endless minor diversities, being nevertheless in all instances precisely the same.

Lastly the means by which that peculiarity of composition and of structure is produced which is so remarkable in all organic substances, are like the results themselves quite peculiar, and bear little or no resemblance to any artificial process of chemistry. We have not in artificial chemistry, any control over individual molecules; but are obliged to direct our operations on a mass formed of a large collection of molecules. The organic agent on the contrary, acting with an apparatus of extreme minuteness, is enabled to operate on each individual molecule separately; and thus according to the object designed, to exclude some molecules, and to bring others into contact. In these processes, it may be conceived that the molecules thus appropriately brought together, and at the same time guarded from extraneous influence by the organic agent, are in virtue of their own proper affinities, sufficiently disposed to unite without requiring that any new properties should be communicated to them.

Such is a brief sketch of what organic agents do, and of what they cannot do; such also the general modes of their operation. We are now prepared to inquire a little more closely into the nature of organic agents.

§ 2.—*Of the nature of Organic Agents.*

The intimate nature of the organic agent or agents, or by whatever other name we may choose to designate the peculiar energies which exist in plants and in animals, and by which they are distinguished from inanimate matter, is now and probably will ever remain altogether unknown to us. But though we be thus ignorant of what these agents are, we can not only comprehend with tolerable certainty what they are not, but as we have seen we can also in some degree ascertain what they are capable or incapable of effecting.

When we were treating of inorganic elements and agencies, and of the laws which these elements and agencies appear mutually to obey, we found that though their nature be obscure and the investigation of them very difficult, we were nevertheless enabled to adduce some not altogether unplausible conjectures on the modes in which the elements combine to form regular crystals and the other conditions of inanimate matter. Now with this insight into the nature of inorganic operations, and with all the additional knowledge of every kind we can command, let us attentively survey the most simple plant or animal; let us observe the actions, the changes, the modifications of form and properties it continually exhibits; and then let us seriously ask ourselves, whether everything we know will enable us to make even an approach toward an explanation of what we see. It is indeed true, that the plant or animal we examine is composed of charcoal and water, and of other ingredients with which we are equally familiar; that it is liable to be affected by Heat, Light, Electricity, and by other inorganic agents. But it is perfectly ascertained that these elements and agents, out of an organized body, and left entirely to themselves, never would or could unite, either in virtue of their own properties or from accident, so as to form any plant or animal however insignificant. Are we not then compelled to infer, that within a plant or animal there exists a principle or agent superior to the agents whose operations we witness in the inorganic world, and which agent moreover possesses under certain restraints the power of con-

trolling and directing the operations of these inferior agents? That this is a natural and a just inference, no one who calmly views all the circumstances will ever deny; and if the existence of one such agent be admitted, the admission of the existence of others can scarcely be withheld; for the existence of one only is quite inadequate to explain the infinite diversity among plants and animals. Thus in the words of the excellent Paley, "there may be many such agents, and many ranks of them:" in other words, there may be an ascending gradation of these agents, from the vital agent in the comparatively simple plant, onward to that of the most complicated animal.

Such being the suggestions concerning organic agency, which arise from a general survey of organic operations, let us with reference to the further bearing and tendency of these suggestions, examine more in detail the nature of organic agents, and the modes of their operation.

To enumerate all the hypotheses that have been framed to account for the phenomena of vegetable and animal existence would be foreign to our purpose; we shall notice therefore only a few of the most remarkable of these hypotheses, for the sake of contrast and illustration in stating our own views.

The chief hypotheses which have been framed to account for the phenomena of vegetable and animal existence may be classed under the following heads:—

The hypothesis—that the lowest kind of vitality, or irritability as it is termed, is the result of certain aggregations of inorganic matters; and that this lowest kind of vitality or irritability is a "property which when acted on by appropriate powers, is competent to give rise to that series of actions in which life consists; in other words, as more explicitly stated by an advocate of this hypothesis, that "as one specific property, namely irritability or vitality, which is common to organized matter in general, qualifies it when subjected to appropriate stimuli to manifest those ruder and less elevated actions which constitute life; so other specific properties peculiar perhaps to certain forms only of such matters, may qualify them when properly acted upon, to display those more delicate and dignified

actions, in which sensation and thought respectively consist."*

The hypothesis nearly related to the preceding,—that the phenomena of vitality are the result of certain "laws of developement" originally impressed on matter, by which in course of time organized beings have been gradually raised through all the stages of existence, from the most simple to the most complicated—for instance, that dogs have been gradually transformed into apes, apes into men, &c.

The hypothesis—that vital forces or agency are not independent forces, but forces superadded to and in some way dependent on the common forces of matter; and

Lastly, the hypothesis of organic agents, *i.e.* of independent intelligent agents, superior to and possessing the faculty of directing and controlling the common forces of matter, so as to cause these forces to associate material elements into the organized, instead of the crystallized condition.

Of these hypotheses we have always adopted the last, viz., the hypothesis of organic agents. This hypothesis variously modified, is not only the most ancient, but with some reserve and under different disguises, is that which is most generally entertained by physiologists to the present time. The other hypotheses are of comparatively recent origin, and have been more or less exclusively maintained by certain modern physiologists.

The term "organic agent" adopted in this volume, always implies an "intelligent agent;" that is "a conscious being possessing knowledge, will, and power."† Now in maintain-

* See Rudiments of Physiology. By John Fletcher, M.D. Part I. page 11.

† See Book I. page 32. To prevent misconception we shall remind the reader of the meanings attached to the following terms:—

Power as applied to an intelligent agent (unless otherwise expressed) is intended to convey a twofold meaning, viz. the common meaning of physical force or power, and the meaning of capacity or power of wielding physical force. No ambiguity can arise from using the word in this double sense, as the two things intended to be expressed always coexist in an intelligent agent. We have adopted this double

ing that intelligent agents are resident in every organized being, we seem to adopt only that common sense view of the matter which all tacitly admit when they speak of living plants or animals. The hypothesis however enunciated in plain terms has been considered to present so many difficulties that whatever be their private opinion, few have openly maintained it. We shall attempt to show that the difficulties alluded to are more apparent than real, and that the hypothesis is less at variance with the truths of philosophy and of religion than either of the hypotheses above enumerated.

We have seen that plants and animals are distinguished from inorganic bodies by the peculiarity of their composition. That is, plants and animals consist of material elements associated in modes, which of their own accord and under the natural operation of their own laws, material elements would never adopt. We say of their own accord, because we admit that material elements and material forces properly directed are fully adequate to produce organized beings considered as mere chemical compounds, without assuming the agency of vital forces. We admit also that heat, light, electricity &c., are constantly influencing, and even necessary to the existence and developement of living organized beings. But these are not the questions. The questions are, by what agency are material elements appropriate to organization selected in preference? by what agency are these appropriate elements so brought together as to combine into organized bodies? who or what contrives, who elaborates all the wonderful mechanism by which the higher organic processes are accomplished? Have we not in these operations clear vestiges of a will to choose what is known to be fitted for a particular purpose—of a power to apply what is known to be thus fitted, and what is willed to be applied to such purpose—in short all the requisites of intelligent agency.

sense to prevent the necessity of circumlocution, or the introduction of a new term.

Organized beings include plants and animals.

Organic agent equivalent to intelligent agent (as in text.)

Intelligent being, as opposed to intelligent agent, intended to denote a being possessed of knowledge, but without power or will.

Those who contend that material forces, or any assumed vital forces, can do all these things, and that life is the mere result of their being done or of organization, must contend therefore for the position, that material or such assumed vital forces possess intelligence and are capable of self-control. We leave the advocates of such opinions to make the best they can of their argument, and fearlessly assert in opposition—that material forces as fixed by the Creator, are never suspended or changed even by Himself;—that matter and material forces when properly directed, are fully adequate to form organized bodies, thus rendering the assumption of vital or any other forces unnecessary; and finally,—that material forces fulfil the will of the Creator in organic processes, without any knowledge or will of their own, and are mere brute forces, which left to themselves, so far from forming organized beings, the moment vitality ceases are actively employed in destroying organization.

Seeing then that organized beings from the lowest to the highest are formed on principles essentially different from inorganic compounds, and that nothing short of the supposition of an active intelligence can explain organization, the question arises—in whom or in what is this intelligence vested? That this intelligence is vested in the great Source of all knowledge and of all power, we do not doubt; but does He act immediately himself, or mediately through the intervention of delegated existences? To Him as Creator the questions of immediate and mediate agency are virtually the same; but we agree with the excellent Paley in thinking that the mediate agency of the Deity is in general most in accordance with natural operations. That having "fixed certain rules, and if we may so speak, provided certain materials, He afterwards committed to other beings, out of these materials and in subordination to these rules, the task of drawing forth a Creation." Nor is the hypothesis of mediate agency in any way derogatory to the Deity, but the reverse; inasmuch as the creation of an intelligent agent capable of accomplishing His purposes, conveys to us a more exalted notion of His power than the accomplishment of His purpose by Himself.

Admitting then that the Deity acts through the intervention of delegated existences, and that neither matter nor

material forces nor any assumed vital forces can be supposed to possess intelligence, we are driven to the assumption that this intelligence is vested in immaterial conscious beings; in other words, that one or more agents possessing knowledge will and power exist in every organized body from the lowest to the highest.* In its lowest grade, the knowledge and operations of such agent may be supposed to be confined to the properties of the material elements adapted for organization, which it has the knowledge to select, and the power to form into an apparatus enabling it to organize other matters and effect ulterior purposes. Where the operations of this primary organic agent terminate, those of another and higher organic agent may be supposed to begin; which by carrying the general process of organization a step further, adapts the organized material for the operations of a third and superior agent. Thus each new agent may be supposed to possess more or less control over all the agents below itself, and to have the power of appropriating their services, till at length in the combined operations of the whole series of agents at the top of the scale, we reach the perfection of organic existence. As we have said, the excellent Paley sanctions this view of organic operations, and continues in the following words: "We do not advance this as a doctrine either of philosophy or of religion, but we say that the subject may safely be represented under this view."

Having stated our hypothesis we shall shortly consider its difficulties and the objections that have been urged against it. This will afford us an opportunity of elucidating some other points connected with the subject.

Objectors to this hypothesis triumphantly ask at the outset, what is an organic agent? where does it exist? what are its properties? And the inability to answer, is in their estimation a satisfactory proof of the absurdity of the hypothesis. But the absurdity lies not in assuming

* The intelligence of inferior agents is usually termed instinct to distinguish it from reason, peculiar to man; and those who prefer this term, may here substitute instinct for intelligence. According to our views instinct and reason are both alike intelligence; but intelligence differing with regard to its object, and in its degree. This we believe is now a common opinion among philosophers.

that immaterial agents exist, but in requiring categorical predications respecting such existences. This will be doubtless considered an evasive answer; or if admitted, objectors go on to ask, are organic agents capable of a separate existence? or do they perish with the organized being they have fabricated? If capable of a separate existence, putting out of question how and where, what is to be said of their numbers both in kind and degree? Strictly speaking, these questions like the preceding and indeed all other questions relating to immaterial existences, are beyond our powers; but as much that is erroneous has been said and written on these and allied subjects, we shall briefly notice them—premising again, in the words of Paley, that what we advance is not to be considered as doctrines either of philosophy or of religion, but as assumptions not opposed to either, and fairly deducible from natural phenomena.

First. That organic agents are as numerous and as varied in degree as organized beings, and that they have a distinct existence when allied with matter will not we presume be denied. The questions then arise—is it probable that organic agents have an existence separate from matter? and if so, do organic agents in their presumed abstract condition maintain their discrete existence, not only individually but in all their varied degrees?

Every one admits that the personal feelings and character of himself is much influenced by the condition of his organization in youth and in age; yet under these and still greater diversities, no one questions his own identity, nor is such identity questioned by others. Now as the matter of which an individual consists is many times changed between youth and age, personal identity can hardly be supposed to be vested in matter or in its properties; but in something that has existed continuously through all these changes: What is this something? We assume this something to be an immaterial agent; and if this immaterial agent can maintain its identity through all the varied changes of matter and of organization, and thus virtually demonstrate its independence of matter, why may it not maintain its identity separate altogether from matter?

When speaking of intelligent agents we alluded to the

possibility as well as the probability of the existence of intelligent beings, as distinct from intelligent agents, *i. e.* of beings possessed of knowledge without will or power,—the other two faculties requisite to constitute an intelligent agent. Now to revert to the above question—why may we not infer that an organic agent on being separated from matter, passes from the condition of an intelligent agent to the condition of an intelligent being, maintaining a species of consciousness, (the primary element of knowledge) without will or power.* No valid objection as far as we are aware can be made to this assumption: admitted however, it leads to other questions of great moment which next claim our attention.

Secondly. Hitherto we have considered the subject of organic agents in general, and barely alluded to their difference of rank. But if the existence of intelligent beings (the representatives of organic agents separate from matter) be conceded, the existence of differences of rank among such intelligent beings must be likewise conceded.

The ranks and grades among organic agents are doubtless as numerous as the ranks and grades among organized beings; but organic agents have been, and as far as our present views are concerned may be classed under three grades. Organic agents strictly so called, the immediate fabricators of plants and animals; Animal organic agents; and the Intellectual agent peculiar to man, which properly speaking ought not to be classed with organic agents, since it cannot be shown that the intellectual agent in man has anything to do with the structure of his corporeal frame. In man as we have said, all these three agents co-exist. The organic agent or agents strictly so called, the immediate fabricators of his body, whose intelligent agency consists in wielding material forces, and by their aid of organizing matter into the primary condition of irritable cells? Various agents of higher rank having the capacity of controlling organic agents and of modelling the primary irri-

* We have said a species of consciousness because the consciousness of an intelligent agent associated with matter may well be supposed to be different from the consciousness of the same agent or being separate from matter. In what the difference consists is of course beyond our comprehension.

table cells into masses and forms suited to their purposes; and lastly the intellectual agent, who capable to a certain extent of influencing all below itself, employs the organized machinery constructed for its use and suited to its exigencies by the inferior agents, and thus becomes the organized being man.

It is consistent with our notions of the wisdom and goodness of the Deity to suppose that He would confer on organic agents an existence, both as to kind and permanence, suited to their rank as intelligent beings. On this ground not only the lowest organic agents, but those agents of animal rank whose intelligent faculties are obviously limited to this earth, may fairly be supposed to have an existence commensurate only with this earth. But the intellectual agent in man, soaring as it does to other worlds and recognizing the existence and attributes of the Deity Himself, even by the aid of an imperfect and mortal machinery, may surely be presumed to be immortal—may surely be presumed at some future time to become united with materials of a higher order, and in the capacity of an organized being, to execute through eternity as before in time, the will of his Creator.

Thirdly. The next point claiming our attention is the developement and decay of organized beings.

When alluding to the facts of Geology and the inferences deducible from them, we noticed the developement of organized beings in connexion with the developement of the earth's condition—facts on a large scale closely analogous to the developement and decay of individual organic existence, we shall therefore consider the two subjects together.

The creation of organized beings according to our limited faculties, admits of a two-fold assumption. We may suppose with some, that intelligent beings were created when matter was created, and remained dormant as intelligent beings till the circumstances of the earth favoured their union with matter, that is their existence as organized beings; or we may assume with others, that intelligent beings were created at the periods when the condition of the earth favoured their union with matter, and their existence as organized beings. Now as between these two

assumptions, there is only a difference of time, and as regards a Being who always is, questions of time are inapplicable, the two assumptions with reference to the Deity are absolutely the same. To us limited beings the decision is beyond our powers, and indeed concerns us not.

Nearly the same remarks may be made regarding the reproduction of organized beings. Intelligent beings are located in germinal cells, or in whatever primary forms organized beings may exist, and as the requisite machinery is gradually evolved, become organized beings. If therefore any part of the machinery be wanting or be imperfectly developed, the corresponding faculties of the organized being will be wanting or imperfect; that is to say, will remain dormant in the same condition in which they existed in the intelligent being.

In the consideration of the death and apparent extinction of organized beings, the attributes of the Deity, as deducible from His works, must be again taken into account.

The end and object of Creation are known only to the Creator Himself. But the supposition clashes with no Divine attribute recognized by man—that one object of creation has been to bring intelligent agents into connexion with matter; and thus not only to make them acquainted with matter, but to demonstrate to them as inhabitants of the world He has created, the Creator's will and power. If this assumption be conceded, we may further assume another object to have been, to grant the same knowledge to a number of organized beings commensurate with the magnitude of His design; and as the earth is a limited field of operation for an infinite agent, this object would be best attained by limiting the existence of organized beings, and by successively bringing others into being. These views while they exclude the ancient and not entirely exploded doctrine of Metempsychosis, at the same time point to arrangements by which many other objects connected with the great scheme of creation are probably attained.

Before proceeding to the reflections suggested by the wonderful phenomena of organic existence, we shall recapitulate the principal points we have been considering, chiefly

for the sake of viewing them in a different light and of offering some supplementary remarks.

1. In organized beings no less than in the operations of the agencies by which organization is effected, we recognize a certain limited choice of action—in short a will to do or not to do certain things, and without which faculty of choice we could scarcely conceive the existence of organized beings, or at least the maintenance of their existence. This faculty (by which in a special manner organized beings are distinguished from inorganic matters) has been recognized from the earliest times, and received various appellations, as *vis conservatrix naturæ*, *vis medicatrix naturæ*, &c.; terms expressive of a will or choice to preserve existence, to restore injuries threatening the extinction of existence &c., which no one would think of applying to inorganic matters. Now will or choice as we have said, is the offspring of knowledge on the one hand, and of power on the other—faculties together constituting a conscious intelligent agent—such an agent in short, as we have assumed on these grounds to exist in every organized being. We have attempted to show that the assumption of such an intelligent agent is not derogatory to the Deity, inasmuch as the creation of an intelligent agent capable of performing a given act, is at least equivalent to self-action. The view of the subject as a whole, may be thus illustrated. The Deity is not the immediate artificer of a steam-engine; but He has created matter with certain properties; He has created man an intelligent agent, and imparted to him a knowledge and faculty of wielding the properties of matter; and having done this, He has left it to the will and agency of the man to construct the machine.

2. The notion conveyed by the term law implying a fixed rule of action, is absolutely incompatible with choice or will. For instance the laws of inorganic nature, as those of gravitation, are not only invariable but are never infringed even by the Deity Himself. He has indeed so admirably contrived these laws, that they act together on the whole conservatively, but not in virtue of any will or choice of their own.

3. Since choice or will is implied in all organizations, and since laws are incompatible with choice or will, all hypo-

theses assumed to explain organization by laws, whether by laws of matter or by what are called laws of developement, must be rejected. We cannot for instance, suppose that matter in virtue of its own laws can form plants or animals; or admitting for the sake of argument that matter can form plants and animals, that vitality is the result of such formation. Neither can we admit that vitalities of an inferior order, as for instance the irritability (or vitality) of cells, can ever so combine or become associated as to form vitality of a higher order; or that the intelligence of a dog or of any number of dogs however associated, either now or hereafter can ever become equal to the intelligence of an ape or of any superior animal, much less of man. We are driven therefore irresistibly to the conclusion that when a new and specific organized being is required, a new and specific act, equivalent to an act of creation, must be performed.

4. An objection to the hypothesis of organic agents not noticed in the preceding pages, remains in the last place to be briefly considered. Objectors argue that by the hypothesis of intelligent agents, we put a stop to all philosophical inquiry into organic phenomena. Such an objection is perfectly unfounded. In accounting for the phenomena of life, it is absolutely necessary to assume the existence of some agency different from and superior to those agencies which operate among inorganic matters. By assuming the existence of intelligent agency, we assume once for all; and avoid the inextricable difficulties arising from attempts to refer organic processes to material forces, or to any assumed vital forces or laws of developement. According to our views, the legitimate object of philosophy is to investigate the phenomena of nature—to find out what is done—whether by the Deity Himself—by the intervention of intelligent agents—or by the medium of the laws He has impressed on matter—in short to trace and refer all we see to its proper source, and as far as our limited faculties will admit, to deduce from the whole of natural phenomena the attributes of their Great Author.

In regarding the nature and composition of organized bodies, the first circumstance which arrests our attention is the wonderful adaptation of the elements and agents of

inorganic and of organic nature to each other. For example, had not carbon and azote and water been formed with the properties which they now possess, organic agents as we know them would have existed in vain; and without organic agents, the properties of these element would equally have been useless. And how truly wonderful and utterly beyond our comprehension, are the properties and adaptations displayed in the processes of organization! To enable ourselves to form some conception of these processes, by bringing to a level with our understanding those things which they accomplish, let us propose to ourselves the question—What ought to be the inherent properties and the constitution of an elementary principle, which should not only be capable of being formed into the hardest and the softest bodies in nature, but which should also be capable of entering as an essential ingredient into substances so very unlike as sugar, vinegar, wood, oil, albumen, and many others, in all their countless forms and varieties? Do we not feel all our fancied knowledge annihilated by such a question? Nay what is more, even when the question is answered for us, and when with the utmost care and to the furthest extent of our ability, we have studied all the chemical properties of Carbon—the substance by which the conditions of the question are fulfilled, how totally unable are we to explain these properties or even to trace them through their simplest modifications? Why for instance, is the diamond capable of assuming the form of charcoal; or why has charcoal been capable of assuming the form of the diamond? And how are these properties of carbon modified and altered in all the numerous states of combination into which we know carbon enters? On what property or quality not possessed by other elements, do all those astonishing capabilities of change depend, which are inherent in this element carbon? And why has carbon been chosen for forming organized beings, in preference to silex or iron or any other element?*

* Since there is nothing peculiar in the elements of which organized beings are composed, and no reason can be assigned why carbon and other elements have been chosen for their formation, we are compelled to ascribe the choice of these materials to the will of the Great Creator. But as He never acts without a purpose, we cannot doubt that these elements have been selected for some specific designs; which design

To us all these things are absolutely unknown; but what a conception do they give of that inscrutable agency by which the elements are governed, of the powers of that Almighty Mind who is conversant with them all—by whom they were first designed and by whom they have all been created! How infinitely must His knowledge surpass whatever we can imagine, how far is His power beyond our utmost calculation!

On the other hand, if the properties of the elements of matter be wonderful, yet more wonderful are those agents within organized bodies by which the elements of matter are directed. With the intimate nature indeed of these agents, we have not the remotest acquaintance, nor probably ever shall have. But as has been already stated, we can trace to a certain extent the laws of action which organic agents have been taught to obey; we observe the unvarying selection by these agents of carbon, azote, and water, on which they chiefly act; their power within certain limits, of guiding and controlling inorganic agents: and more than all, that mysterious periodic developement and decay, which every organized being undergoes. These fact which continually present themselves to our notice, are totally inexplicable according to those laws by which inorganic bodies are governed, and are referable only to an order of existence whose nature has not been revealed.

Lastly, we cannot close this chapter without pointing out to the reader a very remarkable contrast, in the two classes of objects which have engaged our attention. The number

has probably been, that the fabric of the beings dwelling on this earth might be adapted to its general position in the Solar system. When we consider that the same heat and the same light are diffused by the same central sun, and the whole system obeys the same laws, and that the different planets influence, and are influenced by each other, we are warranted in believing that the planets are essentially composed of the same elementary principles. But admitting that the heat and light of the sun are distributed according to the laws which they seem universally to obey, the heat in Mercury close to the sun, and the cold in Saturn at the other extreme, must be alike so intense that organized beings such as inhabit this earth could not exist for a moment. In the different planets therefore, may not organic agents be attached to different elements more or less fixed or volatile, as the distance of the planet from the sun may require.

and diversity of organic agents appear to be endless; in the creation therefore of these agents, the Great Author of Nature has chosen to manifest his attribute of infinity. But in the creation of the material elements which compose the frame of organized beings, He has adopted a plan directly opposite. Instead of different principles, the same carbon the same azote the same water enter into every living being, from the lowest plant upward to man. Amidst the wonders of creation, it is perhaps difficult to say what is most wonderful; but we have often thought that the Deity has displayed a greater stretch of power, in accommodating to such an extraordinary variety of changes, a material so unpromising and so refractory as charcoal, and in finally uniting it with the human mind, than was requisite for the creation of the human mind itself. But to Him all things are alike easy of accomplishment; and He doubtless has willed these and other proofs of His omnipotence, in order to convince us of this truth,—that the Creator of the mind could alone have created the matter with which the mind is associated!

CH. II.—OF THE MODES OF NUTRITION; COMPRISING A BRIEF DESCRIPTION OF THE ALIMENTARY APPARATUS, AND OF ALIMENTARY SUBSTANCES IN PLANTS AND IN ANIMALS.

THE subsistence of all organized beings is derived from sources external to themselves; and the sources of their aliment as well as the modes in which these aliments are applied, exhibit an almost endless variety. As might be expected, the widest differences both in the nature of the alimentary substances, and in the manner of their introduction, are between plants and animals. We shall therefore consider the subject of nutrition under these two heads.

§ 1.—*Of the Modes of the Nutrition of Plants; and of the Nature of those Matters by which their Nutrition is effected.*

A minute investigation of the anatomy and the physiology of plants would be quite foreign to the object of this

treatise. At the same time, it is necessary that the reader should have some insight into these departments of knowledge, in order that he may be enabled to understand the collateral researches which it is our duty to illustrate.

"If we reflect upon the phenomena of vegetation," says Professor Lindley, "our minds can scarcely fail to be deeply impressed with admiration at the perfect simplicity, and at the same time faultless skill with which all the machinery is contrived upon which vegetable life depends. A few forms of tissue interwoven horizontally and perpendicularly constitute a stem; the developement by the first shoot that the seed produces, of buds which grow upon the same plan as the first shoot itself, and a constant succession of the same phenomenon, causes an increase in the length and breath of the plant; an expansion of the bark into a leaf, within which ramify veins proceeding from the seat of nutritive matter in the new shoot, the provision of air passages in its substance, and of evaporating pores on its surface, enables the crude fluid sent from the roots to be elaborated and digested until it becomes the peculiar secretion of the species; the contraction of the branch and its leaves forms a flower, the disintegration of the internal tissue of a petal forms an anther, the folding inwards of a leaf is sufficient to constitute a pistillum, and finally the gorging of the pistillum with fluid which it cannot part with causes the production of a fruit.*

The "crude fluid sent up from the roots" of plants, or their sap as it is termed, is found to consist chiefly of water mucilage and sugar, with some minute portions of other substances containing azote and the saline matters formerly described as incidental to plants and animals. Though under certain circumstances moisture is absorbed by the leaves of all plants, yet there can be no doubt that a great part of the water they contain, as well as certain nutritious matters to be presently mentioned, enter by their roots; not however by the whole root indiscriminately, but chiefly by the minute parts termed spongioles. Hence these minute fibrous parts are of the utmost importance in the vegetable economy, and ought to be carefully preserved in transplantation, otherwise the plant will certainly perish.

* Introduction to Botany, p. 216.

In some instances, roots appear to be intended to act as reservoirs of nourishment for the support of the plants of the succeeding year, on their first developement. There are such roots in the Orchis and Dahlia tribes, and in others.

The aliments of plants are of two distinct kinds, and are appropriated in two distinct modes. The first kind of aliments contain azote, the second kind consists of carbonic acid. Both of these aliments are probably taken up from the soil along with water by the roots; but the aliments containing azote are principally taken up by the roots, while carbonic acid is for the most part appropriated from the air by the leaves.

The chief ingredient in the aliments of plants containing azote, appears to be ammonia. Nay some have gone so far as to assert that ammonia is the only azotized substance appropriated by plants. We consider this however to be a mistake; and have no doubt that various compounds of azote with oxygen as well as with carbon and hydrogen, are also appropriated if not by all plants at least by many species.

The azotized elements of plants, as we have just stated, are chiefly taken up by the spongioles of the roots of plants, which therefore perform an office very analogous to the vessels termed lacteals and absorbents in animals to be afterwards described. The carbonic acid as we have said is taken up chiefly by the leaves, and in the following manner:—

During the day and particularly during sunshine, the leaves of plants have the power of abstracting carbonic acid from the atmosphere. The carbon of the acid and perhaps also a little of its oxygen combine with the plant, while the greater part of the oxygen remains and is diffused through the atmosphere in a gaseous state. During the night on the contrary, or in the shade, plants in general convert a portion of the oxygen of the atmosphere into carbonic acid; but the quantity of oxygen thus converted into carbonic acid is less than the quantity of oxygen separated from the carbonic acid which plants decompose under the influence of the solar light. At the same time with this formation of carbonic acid during the night, plants are said also to absord from the atmosphere a certain portion of oxygen, to

replace that oxygen which had been given off during exposure to sunshine on the preceding day. Plants absorb carbon as long as they are exposed to the light; during the season therefore when the day is long and the night is short, plants give off much less carbon than they absorb. This excess of the absorption of carbon is probably one reason why in the Polar latitudes the progress of vegetation is so rapid. By a beautiful provision of nature, in the course of a short summer of a few weeks, but of unvarying light, plants in these latitudes go through all the changes which in hotter climates require many months.

The late Professor Burnett explained the functions of leaves, by referring the phenomena to the respiration and digestion of plants. The process of respiration in plants is supposed to be continual, and to be accompanied as in animals, by the formation and emission of carbonic acid gas. The process of digestion in plants on the contrary, takes place only during their exposure to the light of the sun; their digestive process consists in the decomposition of the carbonic acid gas of the atmosphere, and the absorption of the carbon from the acid which is thus decomposed. Hence a plant under the influence of sunshine, purifies the air by digesting the carbonic acid, and appropriating the carbon; while in the dark, the digestive process of plants ceases; but they continue to respire without intermission, and carbonic acid gas is thus accumulated in the surrounding atmosphere.

The hypothesis of Professor Burnett is plausible, and may be in part correct. Strickly speaking however, there probably exists in animals no function precisely analogous to the function performed by the leaves in plants. The leaves have been called the lungs of plants, but very erroneously. The function in animals perhaps most nearly approaching to the function of the leaves in plants, we have often thought to be performed by the liver; which as we shall attempt to show hereafter, is the organ in animals more especially concerned in the assimilation of aliments in which carbon predominates.

From the phenomena of gaseous absorption in plants, it seems to be performed by a portion of the leaf peculiarly organized, and situated immediately under the external

covering or epidermis. Gaseous secretion, granting its existence, is probably effected by quite a separate structure. A careful microscopic inquiry into the structure of leaves might throw much light on their physiology.

Another function of plants somewhat analogous to an animal function, seems to be performed by their roots. It has been established that the roots of all plants besides imbibing water and a certain portion of nourishment, perform also an excretory office; and that in the soil in which plants grow, there are deposited by the roots certain matters of an excrementitious nature injurious to the plants from which they have been separated; and which matters therefore cannot be absorbed again, till they have undergone decomposition. Such excreted matters have been adduced as one reason why a soil becomes sooner or later, so much deteriorated by any one species of plant, that it will not support other individuals of the same species; whence the necessity of a rotation of crops. Another and perhaps the chief reason why a rotation of crops becomes necessary, is that the continued growth of the same plant exhausts the peculiar incidental elements necessary to its existence. Different plants and animals require different incidental elements; but we have shown that the presence of some such incidental elements appears to be necessary to the existence and developement of all organized beings. A similar exhaustion also of azotized matters may cause a soil to become generally unfertile. To study these deficiencies, and to know how to supply them by appropriate manures, is the business of the agriculturist. The subject of late has deservedly occupied much of the public attention; but a great deal yet remains to be accomplished.

The principal ingredient in the sap of plants, as we have already stated, is water. The quantity of sap in some plants is almost incredible; and not less so is the force with which on the approach of warm weather in our climates, and at the commencement of the rainy season within the tropics, that sap is determined upwards. The general composition of the sap varies considerably in different parts of the same plant. For instance, sap taken from the roots is little more than water; while the quantity of saccharine and other matters contained in the sap increases in its progress

along the stem to the higher parts of the plant. When the sap begins to rise, the leaves at the same time begin to be developed. From the leaves principally the watery portions of the sap are evaporated, and the evaporation is copious and unceasing. The more solid matters thus remain dissolved in a less proportion of water; and after undergoing further changes, in the leaves chiefly as is supposed, these matters are returned along with the remaining water to be deposited for the future uses of the plant in other parts of its structure, where they constitute the numerous vegetable proximate elements briefly described in the last chapter.

The analogy and relation between plants and animals will be resumed after we have treated of animals.

§ 2.—*Of the Modes of Nutrition in Animals; and of the Alimentary Substances by which they are nourished.*

To beings like animals endowed with locomotive powers, the absorption of their nourishment from without would have been exceedingly inconvenient. Animals have therefore been furnished with an additional receptacle and apparatus subservient to nutrition; into which, as inclination or circumstances may prompt them, their food is conveyed at intervals; and from which, after having undergone certain changes, the food is absorbed and distributed over their system, as the exigencies of that system may require. Hence the distinction between plants and animals;—plants absorb their nourishment by external, animals by internal roots or spongioles. We need scarcely remark, that the stomach and alimentary canal with their appendages, are the internal apparatus to which we allude; this internal apparatus constitutes a marked difference between plants and animals.

1. *Of the Organs of Digestion in Animals.*—Among the different tribes of animals, there is an almost endless diversity in the formation of the alimentary organs; and as these organs vary, not only in their own formation, but also with respect to the auxiliary apparatus and appendages of every kind connected with them, any detailed account of the alimentary system would at present be quite uncalled for. In general the alimentary canal of the higher classes of ani-

mals consists of a tube of greater or less elongation, expanded in some parts of its length, terminated at one extremity by a mouth into which the food is received, and at the other by a provision for the removal of excrementitious matters. In some of the less perfect animals, the alimentary canal has only one aperture: in such animals, of course instead of a canal there is a kind of sac. In a very few other animals the alimentary cavity has numerous apertures. In all instances however, and whatever may be the nature of the alimentary matters, these matters after having been retained for some time in the organs appropriated to nutrition, are reduced more or less to a fluid state—are digested in the common sense of the term, and are converted into what is denominated chyme. The more nutritious parts of the fluid chyme, or the chyle as the nutritious parts are denominated, are then absorbed and distributed through the system for the reparation of the animal; while the insoluble and other matters are separated as excrementitious.

We have already alluded to the endless diversity observable in the form and arrangements of the alimentary canal in the different kinds of animals. A few of the most remarkable of these diversities among the more perfect animals, will be noticed in the following outline of the alimentary canal, as existing in the human body.

Of the Mouth and its Appendages.—"In no apparatus put together by art" says Paley, "do I know such multifarious uses so aptly contrived as in the natural organization of the human mouth." "In this small cavity we have teeth of different shape,—first for cutting, secondly for grinding; muscles most artificially disposed for carrying on the compound motion of the lower jaw, half lateral and half vertical, by which the mill is worked; fountains of saliva springing up in different parts of the cavity for the moistening of the food, while the mastication is going on; glands to feed the fountains; a muscular construction of a very peculiar kind in the back part of the cavity, for the guiding of the prepared aliment into its passage towards the stomach, and in many cases for carrying it along that passage." "In the meantime and within the same cavity, is going on another business altogether different from what is here described—that of respiration and of speech. In addition therefore to all

that has been mentioned, we have a passage opened from this cavity to the lungs for the admission of air, exclusively of every other substance; we have muscles, some in the larynx and without number in the tongue, for the purpose of modulating that air in its passage, with a variety a compass and a precision of which no other musical instrument is capable. And lastly we have a specific contrivance for dividing the pneumatic part from the mechanical, and for preventing one set of actions interfering with the other." "The mouth with all these intentions to serve is a single cavity, is one machine, with its parts neither crowded nor confined, and each unembarrassed by the rest."* Such is Paley's graphic description of the human mouth and its appendages; we have quoted it at length as a fine statement of the adaptation of means to ends in the animal structure.

Man has been observed to differ more from other animals in the form of his lower jaw, than in the form of any other bone of his body. This difference consists chiefly in the prominence of the chin, that peculiar characteristic of the human countenance which distinguishes more or less every race of mankind, and is found in no other animal whatever. There is likewise a striking difference among the various tribes of animals in the mode of articulation of the lower jaw, which in all cases is singularly adapted to the nature of the food of the animal. Thus in the carnivorous tribes the articulation is so arranged that the jaw can move only up and down, and is almost entirely incapable of that lateral movement which is essential to genuine mastication. Hence such animals cut and tear their food, and swallow it in large pieces. But animals deriving their subsistence from vegetables, in addition to the vertical motion of their lower jaw have the power of moving it backwards and forwards or to either side, so as to produce a grinding effect admirably fitted for triturating the vegetable matters on which they subsist.

The teeth next claim our attention as being not less suited to the habits of the animal, than the form of the jaw in which they are set. Teeth are divided by naturalists into three orders:—The *Incisores* or cutting teeth, placed in the front part of the mouth; the *Cuspidati*, canine, or

* Natural Theology, chap. ix.

corner teeth, usually placed near the angles of the jaw; the *Molares*, grinding or lateral teeth, which always occupy the sides and back part of jaw. In man and in those animals which most nearly resemble him in their structure, teeth exist of all the above varieties of form. But many species want one or other of these varieties, while the teeth they possess are of a form and size very unlike the same teeth in man. Thus in animals nourished chiefly by the harder vegetable substances, and on account of their peculiar mode of feeding styled gnawing animals, the incisor teeth are the most remarkably developed, as these teeth are the best adapted and indeed are indispensably necessary to their habits. In carnivorous animals on the other hand, the canine teeth are of chief importance as enabling these animals to seize and hold their prey; in such animals accordingly, the canine teeth are the most perfectly formed. Lastly in animals that live on grass and other herbaceous substances, and whose food requires long and complete mastication, the Molares or grinding teeth attain the greatest enlargement; and in many of these animals the incisor and the canine teeth are entirely wanting. Besides the adaptation of the form, the enamel or harder cutting portion of the teeth is distributed over and throughout their texture according to their intended uses, in a manner that is truly extraordinary. The description of the arrangement of the enamel, as well indeed as a minute account of the teeth themselves, belong however to the physiologist, on whose province we shall not further intrude. But it is impossible to take even the most superficial view of the teeth of animals, without being struck with the admirable design and fitness they display, throughout their whole fabrication.

The next auxiliary appendages of the mouth are the glands that secrete the saliva, in which we observe the same beautiful arrangement as in the form and structure of the teeth. In man, though the apparatus for the secretion of the saliva is by no means of large size, yet the quantity of fluid which the salivary glands are capable of secreting and do secrete during mastication, is very considerable, often amounting it is said to half a pint or more. This fluid in its perfectly healthy state, is neither acid nor alkaline, or alkaline only in a slight degree; but

occasionally it assumes an acid character. Besides the great utility of the saliva in moistening the food, we cannot doubt that it assists and is even necessary to the full completion of the succeeding digestive process. By a beautiful arrangement, animals which do not masticate their food, as the carnivorous tribes, have very small salivary glands; while in animals whose food requires long mastication, as in ruminating animals—the cow and the sheep for example, the salivary glands are very large.

The passage by which the masticated food is conveyed from the mouth to the stomach, is termed the œsophagus. Like the whole frame, the œsophagus is admirably adapted for its office, and in different animals varies in size and structure according to their habits. These differences however scarcely concern us at present, and we pass on to that important organ—the Stomach.

The human stomach is a membranous bag, of a shape rather difficult to be described, so as to convey a clear notion of it to the reader. If we imagine two cones united at their bases, and the figure thus produced to be bent into a semicircular form, some idea may be obtained of the outline of the stomach in the human species. In respect to its size the human stomach varies; but in the adult its capacity is usually such as to contain about two or three pints. The stomach is situated immediately under the diaphragm; but the precise place of the organ differs somewhat with its state of repletion. The general position of the stomach is transverse, or horizontal, supposing the body to be upright; the left orifice or cardia, which communicates with the œsophagus, being somewhat higher than the right orifice, the pylorus, through which the food is transmitted to the further portion of the alimentary canal. The upper space between the two orifices is usually termed the small curvature, the lower space the great curvature of the stomach. Numerous glands occupy the internal surface of the stomach, particularly near its pyloric orifice. By these glands a fluid is secreted of the highest importance in the digestive functions. On the nature of that fluid we shall enlarge hereafter.

Such is the stomach of man: but in other animals, the form and the magnitude of the organ vary almost infinitely

according to the nature of their food, and various circumstances. We can at present notice only two or three of the most remarkable diversities. The stomach of most carnivorous animals bears a resemblance to the stomach of man. There is also a resemblance at least externally in certain herbivorous animals, as in the horse, the rabbit, and others. The internal arrangements however are dissimilar; thus in the herbivorous animals we have mentioned, the left or cardiac half of the stomach is lined with cuticle; while the other half, toward the pylorus, has the usual villous and secreting surface. Hence these two portions of the stomach perform very different offices, and generally contain food in very different states of reduction. But the most complicated and artificial arrangements, both with respect to the structure of the parts and the lining membranes, are found in the well-known four stomachs of animals that ruminate and have divided hoofs, as the cow and the sheep. We shall endeavour to give a general description of these four stomachs. The first stomach is denominated the Paunch, and in the adult animal is by far the largest. The second stomach follows and may be regarded as a globular appendage to the paunch, from which it is distinguished principally by the regular and beautiful distribution of its internal membrane into polygonal cells. The third stomach is the smallest of the four, and is the most remarkable in its structure; its capacity is much diminished by numerous and broad duplicatures of its internal membrane, which are placed lengthwise and vary in breadth in a regular order. The fourth stomach is next in size to the paunch, and is lined with a villous membrane, similar to the villous membrane of the human stomach, which this fourth stomach may be supposed to represent; the three preceding stomachs having been evidently intended to prepare the refractory food of the animal for the true digestive process, undergone in this last stomach. Every one is acquainted with the fact that animals furnished with the gastric arrangements above described, ruminate; that is to say, have the faculty of masticating a second time and at their leisure, the food which had been hastily swallowed and deposited in their first stomach. The contrivance by which rumination is effected is very beautiful,

and is connected with the peculiar arrangement already mentioned of the four stomachs with respect to the œsophagus; but as it would not be easy to give in few words more than a general outline of the stomachs of ruminating animals, for a particular description of them we must refer the reader to anatomical works. The only other modification of the stomach we shall notice, is that which exists in some birds, as for example in the common fowl. The common domestic fowl as well as many similar birds, has a sort of preliminary stomach termed the crop, formed by an expansion of the œsophagus. In the crop, the hard seeds and other compact substances birds devour, are macerated and softened and perhaps undergo further changes before they enter the proper stomach, to be next considered. The proper stomach or gizzard of birds, is a hollow muscle of great strength, lined with a firm and thick epidermis disposed in rugæ, and admirably adapted for triturating the hard matters which constitute their food. The small stones these birds constantly swallow, seem also to promote this trituration.

We have given the above short sketch of the structure of the stomachs of animals, not only that we might impart to the general reader a faint conception of the extraordinary design manifested in that structure, but to enable us to show the object of diversity of structure, when we come to speak of the function of digestion a little more in detail.

After the stomach we proceed to the consideration of the Intestinal Canal. In man and in the more perfect animals, this canal assumes two well marked forms, usually termed from their relative size, the small and the large intestines. In most animals resembling man, the small intestines are the longest, and their internal surface is villous. The coats of the larger intestines are thicker, and the membrane with which they are lined is very rarely villous. The first portion of the small intestines, from its supposed length in man termed the duodenum or twelve-inch intestine, begins from the pyloric orifice of the stomach, and in many animals has a course not easy to be described so as to be intelligible to the general reader. The duode-

num terminates in the second portion of the small intestines called the jejunum, from its being usually empty. The duodenum is secured in its position by various attachments; in this fixedness the duodenum differs from the stomach and other parts of the intestinal canal, which are comparatively loose and floating. The unaltered position of the duodenum appears to serve many wise purposes on which we cannot dwell here: but one purpose probably is to ensure the easy and regular passage of the bile and the pancreatic fluids into this part of the canal. As the organs producing these important fluids are fixed, the conducting tubes necessarily require also to be connected with a fixed organ, otherwise the passage of the fluids from the secreting organs to the intestine would be constantly liable to interruption. The duodenum is very highly organized, and its functions are probably not less important than even the functions of the stomach. The remainder of the small intestines is divided into the jejunum already mentioned, and the ilium; but the precise place where one ends and the other begins, is scarcely definable; nor are the differences of structure between the two so obvious as to require to be noticed in this place.

The large intestines exceed the small intestines in diameter, but are considerably shorter; their form and structure are also different. The first division of this portion of the alimentary canal is termed the cœcum; and in man at least, may be considered as little more than the head or commencement of the next division of the large intestines termed the colon. The colon is of much greater diameter than any other part of the intestinal canal, and constitutes almost the entire length of the large intestines. The colon begins low down on the right side of the abdomen, then ascending to the level of the stomach, passes across to the left side, immediately below the stomach. On the left side the colon descends again, and at the same time forms what is called the sigmoid flexure. The colon and the alimentary canal at length terminate in what is named the rectum. The texture of the colon is much thicker than the texture of any other portion of the canal. The organization also of the colon is peculiar; and like the

whole arrangement wonderfully adapted for the purposes which this portion of the canal is supposed to fulfil in the animal economy.

Such is a short account of the alimentary canal in man. We shall now state some of the more remarkable diversities observed in the lower animals.

One of the most striking circumstances relative to the alimentary canal in animals, is its various lengths in the different classes. The length of the alimentary canal in man, and in other omnivorous animals, is intermediate to that of carnivorous animals on the one hand, and of herbivorous animals on the other. In man, the whole length of the canal is about six or seven times the length of his body; while in carnivorous animals the canal is only about three or five times the length of their bodies; and in graminivorous animals, as in the sheep, the length of the canal is twenty-seven times that length. In other herbivorous animals, the length of the canal varies from twelve to sixteen times the length of their bodies. In most birds the alimentary canal is much shorter than in quadrupeds, the length in general being between twice and five times that of their bodies; while in many reptiles and fish the length of the canal scarcely exceeds that of the body; in some fish it is even less, as for example in the shark. There are animals, vegetable feeders, the length of whose alimentary canal is not so great as above stated, the deficiency of length being apparently made up in breadth. Thus in the horse, the stomach is simple and not much developed when compared with the size of the animal, nor are the intestines very remarkable for their length; but the cœcum and the large intestines are enormously expanded in diameter. The cœcum of the horse seems to perform many of the offices of a second stomach, and is of fully equal capacity. There are in animals many other beautiful arrangements of the digestive organs which we shall pass without further notice, as our desire is to inform the reader merely of the general connexion and adaptation of the structure of animals to the food on which they live. It remains to conclude this outline of the digestive organs with a few words regarding those almost invariable accompaniments of the alimentary canal, —the liver, the pancreas, and the spleen.

The liver is the largest glandular apparatus in the body; and one of its principal offices is to secrete the Bile, which secretion as before observed enters the intestines near the commencement of the duodenum. The general situation of the human liver is in the upper part of the abdomen, under the ribs on the right side; from whence it extends more or less to the region of the stomach, and in some instances even to the left side. The appearance and form of the liver are too well known to require description here; while to those who are unacquainted with these particulars, they cannot be adequately made known by words. In man and the greater number of animals, the bile is collected in a small bag termed from its office the gall-bladder. The animals wanting a gall-bladder are chiefly vegetable feeders, as the horse and the goat among quadrupeds, the pigeon and the parrot among birds. On the contrary, most amphibia have a gall-bladder; but it exists in few animals lower in the zoological scale. The liver assumes a variety of forms in different animals. In many and particularly in carnivorous animals, the liver is more divided than in man; while in ruminating animals, also in the horse, the hog, and others, its divisions are not more numerous than in man. The liver of birds consists of two lobes of equal size.

The pancreas or sweet-bread, is a large gland which in the human body, lies across the upper and back part of the abdomen behind the stomach, and between the liver and the spleen. The pancreas is composed of numerous small glands, whose ducts unite and form the pancreatic duct. In man the pancreatic duct joins the gall duct at its entrance into the duodenum; and thus the peculiar secretion of the pancreas is poured into that intestine, commingled with the bile. In animals, the pancreas like the liver is much varied in its form; and its duct instead of entering with the biliary duct, often joins the intestinal canal separately, as in the hare and others. In fishes the pancreas is wanting; but what are termed the cœcal appendages are supposed to have a similar office. The nature of the pancreatic fluid will be considered presently.

The human spleen is situated in the upper and left side of the abdomen. Its shape is oblong, and its colour a deep

mulberry; more nearly resembling the colour of the liver than of any other organ. The spleen has no excretory duct; and its use is very little understood. Among the less perfect animals, the spleen is much smaller than in animals whose structure resembles the structure of man; and where there is more than one stomach, the spleen is always attached to the first stomach. The situation also of the spleen varies in the less perfect animals, thus the spleen of the frog is fixed in the mesentery.

We proceed to notice very briefly the peculiar circulation of the blood in the abdominal viscera, together with the character and agency of that portion of the nervous system which is connected with the digestive and assimilating functions of animals.

In the general circulation of the blood through an animal body, a large tube or artery communicating with the heart, is gradually subdivided as it is prolonged from that organ, till its subdivisions finally become imperceptible. The arteries in this state of minute subdivision assume the character of veins. The veins in their progress undergo a change, the reverse of the change undergone by the arteries; they unite gradually, and at length form one or two principal tubes, which proceed to the side of the heart opposite to where the artery originates. Such is the circulation of the blood through the body generally; the circulation through the lungs is merely a repetition of the same arrangement. Throughout the body therefore, the general motion of the blood in arteries is from greater to smaller tubes, while in the veins, the motion is from smaller to greater tubes. By a beautiful provision the veins are also furnished with valves, which most effectually prevent the regurgitation of the blood; without such valves the blood could scarcely flow in a regular stream.

The circulation of the blood through the organs of digestion presents a remarkable exception to the general circulation. The venous blood from the organs of digestion is submitted to a preliminary arterializing process in the liver, before it is remingled with the venous blood from the rest of the body. That is to say, the veins from the organs of digestion unite into one large tube termed the *vena portæ*; which tube entering the liver, is there again subdivided in

the same manner as an artery. These ultimate subdivisions of the *vena portæ* together with the similar subdivisions of the proper artery of the liver coalesce; and from the blood thus mixed, the bile is separated. The coalesced blood vessels assuming the character of veins then gradually unite, and at length form two or three large tubes which empty themselves into the general veins going to the heart; while the hepatic ducts uniting in like manner convey the bile to the gall-bladder. Such are the principal facts connected with the circulation of the blood in the abdominal viscera, and with the secretion of the bile. We shall soon have occasion to bring them to the recollection of the reader.

When treating of organic agents, we noticed the probability of the opinion that in living beings there exists a series of agencies gradually raised one above another, each agency having more or less control over all the agencies below itself. Now in the digestive and assimilating functions, we appear to have as we might expect, the lowest of these organic agencies. The agencies operating in digestion and in the first stages of assimilation are in man, the same perhaps that exist in all organized beings, vegetable as well as animal, and are only a few degrees as it were above the agencies of mere inorganic matter; in other words, those agencies control material forces and cause the primary elements of matter to unite into organized forms. We draw the conclusion that such control is exerted, not less from the phenomena of assimilation than from the peculiar character of the nerves distributed over the digestive organs; the effects of which nerves, as we shall presently endeavour to show, approach more nearly to the effects of common chemical agents than to those of any agent belonging to the animal economy. These nerves compose what from their peculiar structure are termed the ganglionic nerves. In animals of the very lowest kind, the ganglionic nerves alone appear to exist; and though in the more perfect animals, the ganglionic nerves are connected with other nerves of a higher character, the ganglionic nerves always form alone a peculiar system, the functions of which seem to be of the subordinate character above stated.

2. *Of Alimentary Substances.*—It may be considered as a general rule, that organized beings adopt as aliments substances lower than themselves in the scale of organization; or substances which if not originally lower, are in some measure lowered by certain spontaneous changes they undergo. There are of course innumerable exceptions to this rule; but viewing the whole of animated beings, it seems to be a law of nature. Thus plants, and perhaps the very lowest kinds of animals, have the power of assimilating carbonic acid gas; the powers of assimilation of plants and of such animals, may also extend to other inorganic compounds of carbon—indeed plants and zoophytes appear to derive their chief nourishment from matters of that nature.* Higher in the zoological scale, we find that animals of prey almost invariably devour those other animals which are inferior to themselves, either in magnitude, in organization, or in intelligence, till we arrive at man himself. He, as his necessities or his fancies may dictate, appropriates every nourishing substance, even carbonic acid gas, which the human stomach seems to have the capacity of assimilating in common probably with the stomachs of all animals. Of course a lion or even a crab can feed on the body of a man as well as on that of an ox or of an insect. But no one we presume will assert that man is the natural prey or food of these animals, and such alone is the degree of immunity for which we here contend; in all the operations of nature, we must try to discover and bear in mind not the exception but the rule, otherwise we shall be constantly liable to error.

By this beautiful arrangement in the mode of their nutrition, the more perfect animals are exonerated from the toil of the initial assimilation of the materials composing their frame; since the constituent elements of their food are already in that order which is adapted for their purpose. Hence the assimilating organs do not require the complica-

* This remark upon zoophytes must be regarded as applying to the lowest forms of that class as defined by the earlier zoologists; for the zoophytes of modern authors, which correspond to the polypes, have a distinct alimentary canal, and derive their food from organized bodies. Again, those lower organisms which assimilate carbonic acid, have been transferred from the animal to the vegetable kingdom.—G.

tion which would otherwise have been necessary, and much elaborate organization is saved. Striking illustrations of this abridgement of organization are afforded by the differences before mentioned between the assimilating apparatus of carnivorous and of graminivorous animals. According to the scale which this difference exhibits, we can form some conception of the complication which would have been requisite to enable such an animal as man to feed like a plant on carbonic acid gas, or carburetted hydrogen, or on any other simple compound of carbon.

Another great purpose is effected by this arrangement regarding the food of animals; without which, organization as at present constituted could hardly exist. If organized beings did not prey on each other, their remains would accumulate in such quantity as to be nearly incompatible with life, certainly with animal life in its most perfect condition as it is at present known to us. But by the arrangement that animals are food to each other, not only is an opportunity afforded for the existence of a greater number of animals and of a greater variety among them, but the obtrusion of the bodies of animals whose life has become extinct, is entirely prevented; nor is the removal of dead animal matter the only good accomplished, but many other important results are obtained. To enter upon the consideration of these other results would be foreign to our present object. There is however, one consequence of this system of universal voracity which more immediately concerns us, since it is of a nature so comprehensive as to suggest a natural classification of alimentary substances: we allude to the similarity of composition among the staminal proximate elements which constitute the fabric of organized beings.

In the preceding chapter we briefly described the chief proximate elements of plants and animals, under the denomination of saccharine proximate elements, oleaginous proximate elements, and albuminous proximate elements. Without entering again into details respecting these three great classes of proximate elements, we may remind the reader that the saccharine class or group of proximate elements is chiefly derived from vegetables, of which they may be considered as characteristic—that the oleaginous

class or group of proximate elements is common both to plants and animals—that the albuminous class or group of proximate elements, though found in small quantities in vegetables, may be considered as the characteristic proximate principles of animals. Finally, that the albuminous proximate elements differ from the saccharine and oleaginous elements by containing azote. These three great classes or groups of proximate elements together with water, constitute as we have said the four staminal elements of which all organized bodies are essentially composed.

When treating of the three great staminal elements of organized bodies in the preceding chapter, we remarked that without any alteration of their intimate constitution they are capable of assuming an infinite variety of modified forms, many of which are so peculiar, that from their sensible properties it is very difficult to recognize their identity. Moreover, these staminal elements in all their forms are capable of readily passing into one another, and of combining with each other; at least the organic agents as we shall see hereafter, have the power of effecting such changes. Further, these staminal elements are all susceptible of transmutation into other proximate elements, according to certain laws: thus the saccharine element is readily convertible into the acid termed oxalic; or under other circumstances, into the modification of the oleaginous proximate element, alcohol. Though an endless variety of these modifications of the staminal elements exist in different organized beings accompanied by many extraneous matters, still the proportion these modifications of the staminal elements bear to the staminal elements themselves is very limited; and they are either confined to glandular secretions, or are excrementitious, or extravascular; that is to say these modifications and combinations of the staminal elements form no part of the living animal though they are attached to it, as in the case of the various products of secretion, the shells of the molluscous tribes, and many others.

The consequence then to which we before alluded is, that as all the more perfect organized beings feed on other organized beings, their food must necessarily consist of one

or more of the three staminal elements of organization. Hence it not only follows as before observed, that in the more perfect animals, all the antecedent labour is avoided of preparing these staminal elements from the primary elements of matter, but that a diet to be complete, must contain more or less of all the three staminal elements. Such at least must be the diet of the higher classes of animals, and especially of man. It cannot indeed be doubted that many animals on an emergency, have the power of forming a chyle from one only of the three classes of aliments; but that any of the higher animals can be so nourished for an unlimited time, is exceedingly improbable. Nay if we judge according to what is known from universal observation, as well as from experiments which have been actually made by physiologists regarding food, we are led to the directly opposite conclusion; namely, that the more perfect animals could not exist on one class of aliments, but that a mixture of two at least, if not of all the three staminal proximate elements of organic matter, is necessary to form an alimentary compound well adapted to their use.

This view of the nature of aliments is singularly illustrated and maintained by the familiar instance of the composition of Milk. All other matters appropriated by animals as food, exist for themselves, or for the use of the vegetable or animal of which they form a constituent part. But milk is designed and prepared by nature expressly as food; and milk is the only material throughout the range of organization that is so prepared. In milk therefore we should expect to find a model of what an alimentary substance ought to be—a kind of prototype as it were, of nutritious materials in general. Now every sort of milk that is known is a mixture of the three staminal elements we have described; in other words, milk always contains a saccharine element, a butyraceous or oily element, and a caseous or strictly speaking an albuminous element. Though in the milk of different animals, these three staminal elements exist in endlessly modified forms and in very different proportions, yet neither of the three is at present known to be entirely wanting in the milk of any animal.

Of all the evidences of design in the whole order of

nature, Milk affords one of the most unequivocal. No one can for a moment doubt the object for which this valuable fluid is prepared. No one can doubt that the apparatus by which milk is secreted has been formed specially for its secretion. No one will maintain that the apparatus for the secretion of milk arose from the wishes or the wants of the animal possessing the apparatus, or from any fancied plastic energy. On the contrary, the rudiments of the apparatus for the secretion of milk must have actually existed in the body of the animal, ready for developement, before the animal could have felt either wants or desires. In short, it is manifest that the apparatus and its uses were designed and made what they are, by the great Creator of the universe, and on no other supposition can their existence be explained.

The composition of the substances by which animals are usually nourished, favours the mixture of the primary staminal elements forming the basis of their food; since most of the substances are compounds, of at least two of the staminal elements. Thus most of the gramineous and herbaceous matters contain the saccharine and the albuminous elements; while every part of an animal contains at least albumen and oil. Perhaps therefore, it is impossible to name a substance constituting the food of the more perfect animals, which is not essentially a natural compound of at least two if not of all the three proximate elements which afford nourishment to organized bodies. But in the artificial diet of man, we see this great process of mixture most strongly exemplified. He, dissatisfied with the spontaneous productions of nature, culls from every source; and by the force of his reason or rather of his instinct, forms in every possible manner and under every disguise, the same great alimentary compound. This after all his cooking and his art, how much soever he may be disinclined to believe it, is the sole object of his labour; and the more nearly his results approach to this object, the more nearly do they approach perfection. Even in the utmost refinements of his luxury and in his choicest delicacies, the same great principle is attended to; and his sugar and flour, his eggs and butter, in all their various forms and combinations, are nothing

more or less, than disguised imitations of the great alimentary prototype MILK, as furnished to man by nature.*

CH. III.—OF THE DIGESTIVE PROCESS; AND OF THE GENERAL ACTION OF THE STOMACH AND DUODENUM.

WE proceed now to consider the most important function of the stomach; the function namely by which the assimilation of the food is begun. Before that function can be well understood, it is necessary to take into account the influence of the fourth staminal element water in modifying the intimate constitution and the peculiar properties of the other three classes of alimentary substances. We refer the reader therefore in the first place to what has been said on the modifying influence of water in the preceding chapter.

The operations of the stomach viewed as a whole, may be stated as follows:—

First. The stomach has the power of dissolving alimentary substances, or at least of bringing them to a semifluid state. This operation seems to be altogether chemical, and is probably effected by reducing the properties of alimentary substances.

Secondly. The stomach has within certain limits, the power of changing into one another the simple proximate elements of food which have been described in the last

* These views of aliments and of assimilation were first published by the Author in their present form in 1834, and are now generally admitted by physiologists. They had been partially made known many years before the period stated, but attracted little notice in this country till they were adopted by MM. Liebig and Dumas, through whose means chiefly they have become generally known. MM. Liebig and Dumas have attempted to carry these views further; they maintain that the chief or only use of saccharine and oleaginous elements is to produce animal heat by the combustion of the carbon they contain. We dissent from this opinion, for reasons some of which will be subsequently noticed.

chapter. Unless the stomach possessed such a power, that uniformity in the composition of the chyle which we may imagine to be indispensable to the existence of every animal, could not be preserved. This part of the operations of the stomach appears like the reducing process to be chemical, but not so easy of accomplishment;—it may be termed the converting operation of the stomach.

Thirdly. The stomach must have within certain limits the power of organizing and vitalizing the different alimentary substances, so as to render them fit for being brought into more intimate union with a living body than the crude aliments can be supposed to be. It is impossible to imagine that this organizing agency of the stomach can be chemical. This agency is vital, and its nature is completely unknown.

First. *Of the Reducing Powers of the Stomach.*—In order to render more intelligible that function of the stomach, which is performed by means of its reducing power, let us endeavour to trace the series of phenomena which appear to arise during the conversion of simple albuminous matter into the albumen of the chyme, without taking into account any other change.

When milk is introduced into the stomach of an animal as of a dog, it usually becomes solid, or in ordinary language is coagulated. This coagulation is probably a mere chemical change; for the same change would under similar circumstances take place out of the body. That is to say, if milk were mixed with a fluid more or less acid, like the fluid which exists in the stomachs of animals while the food is undergoing the process of digestion, the milk would be coagulated. There may be however and probably is some object in the change produced by coagulation, since the stomachs of animals are fitted to operate chiefly on solid matters. Admitting the object of the change, we can hardly consider the coagulation of milk to be essential for the subsequent processes of its digestion, because gelatine, a staminal element of food nearly resembling albumen in its composition, undergoes under similar circumstances no such solidifying change.

The albuminous fluid milk, which has by the coagulating influence of the juices of the stomach been solidified into

a mass or curd, is soon altered further; more especially that part of the mass immediately in contact with the membrane of the stomach. The curdy mass assumes a gelatinous appearance, then each portion is successively more and more softened, till at length the whole becomes nearly fluid, and after some additional modifications gradually passes into the state of chyme. Through all these apparent changes however, the albuminous element has undergone no real alteration. What was introduced into the stomach as an albuminous fluid, is still albumen in the chyme; at least chemists have pronounced it to be so. Yet the albumen has assumed an appearance altogether different. Albumen or milk out of the stomach, may be coagulated into a comparatively firm solid. The albumen of the chyme is indeed coagulable by heat; but its coagulation is so imperfect and so wanting in tenacity, as to offer a striking contrast with the coagulated albumen of the egg, or solid curd. What then in the stomach has happened to the albumen? Viewing only its susceptibility of coagulation, the albuminous element has merely become chemically combined with a portion of water. The solid albuminous curd has by this combination with water been reduced to the weakest possible state—to the delicate state as it were of infancy; in short, to a state precisely analogous to that of the weak sugars and other organic compounds, comparatively with the strong and perfect varieties of the same substances, as described in the preceding chapter.

Such is we believe an accurate account of the merely solvent or reducing powers of the stomach. We have next to show the means by which solution or reduction is effected.

The process of combining different substances with water, and of thus reducing them from a stronger to a weaker condition, may in some instances and to a certain degree, be effected artificially. But in no instance do we appear to be able to invert the process, or to complete an organic compound, by separating the compound from the water which enters into its composition. For example we can in some respects make a strong sugar weak, but we cannot change a weak into a strong sugar, though such a change

within certain limits seems to be to the organic agents just as easy as the reducing process.

The different operations of cookery, as roasting, boiling, baking, &c. have all a reducing effect, and may therefore be considered as preparatory to the solvent action of the stomach. Of these operations Man's nature has taught him to avail himself, and they constitute the chief means by which he is enabled to be omnivorous; for without such preparation a very large portion of the matters which he now adopts as food, would be completely indigestible. By different culinary processes, the most refractory substances can often be rendered nutritious. Thus by alternate baking and boiling, the woody fibre itself may be converted into a sort of amylaceous pulp, not only possessing most of the properties of the amylaceous element, but capable of being formed into bread.

The culinary art engages no small share of attention among mankind; but unfortunately cooks are seldom chemists, nor indeed do they understand the most simple of the chemical principles of their art. Hence their labour is most frequently employed, not in rendering wholesome articles of food more digestible, which is the true object of cookery, but in making unwholesome things palatable; foolishly imagining that what is agreeable to the palate must be also healthful to the stomach. A greater fallacy can scarcely be conceived; for though by a beautiful arrangement of Providence what is wholesome is seldom disagreeable, the converse is by no means applicable to man, since those things which are pleasant to the taste are not unfrequently very injurious. Animals indeed, for the most part avoid instinctively all unwholesome food, probably because every thing that would be prejudicial is actually distasteful to them. But as regards man, the choice of articles of nourishment has been left entirely to his reason.

In order to illustrate the importance of a judicious adaptation of cookery, we may observe that the particular function of the stomach now under consideration, namely the dissolving or reducing function is liable to very great derangements. In some individuals the reducing power is so weak, that their stomach is almost incapable of dissolving

solid food of the most simple kind. In such a state of the stomach, a crude diet of the flesh of animals in a hardened state, or of other compact substances, is little else than poisonous; while the same animal and vegetable matters often agree well if reduced to a pulpy state. On the other hand as in the disease termed Diabetes, the solvent powers of the stomach are often inordinately increased, and every article of food is dissolved and absorbed almost as soon as it is swallowed. In such cases a diet and a mode of preparation are required, directly the reverse of those which are found to be so beneficial when there is a debility of the solvent powers; and aliments must be chosen which are firm and solid, but at the same time nutritious.

Regarding the intimate nature of the agency by which the combination of alimentary substances with water is effected in the stomach, we cannot be said to possess much certain knowledge. This combination appears to be chiefly owing to the agency of a fluid secreted by the stomach, the glands for the formation of which fluid are most numerous toward the pyloric orifice. The aliment having been previously broken down by mastication, and having received an admixture of saliva and of other fluids, is brought into contact with the juices secreted by the stomach; by this secretion of the stomach or by some other energy exerted in that organ, the food which has been introduced into the stomach is associated with water, and thus becomes itself more or less a fluid. Of this important secretion of the stomach, chlorine in some unknown state of combination is an ingredient: it would seem a necessary ingredient; for the secretion in its healthy state always contains more or less of chlorine, the powerful influence of which primary element seems mainly to contribute toward effecting the union of the food with water.

The chlorine thus so indispensable to the reducing process, is perhaps more frequently the subject of derangement than anything concerned with the assimilation of the food. It often happens that instead of chlorine or a little free muriatic acid, a large quantity of free muriatic acid is elicited, which free muriatic acid not only gives rise to much secondary uneasiness, but more or less retards the process of reduction itself.

The source of this chlorine or muriatic acid in the stomach, must be the common salt which exists in the blood; to suppose that it is generated, is quite unnecessary. The chlorine is therefore secreted from the blood; and it may be demanded, what is the nature of the agency capable of separating chlorine from a fluid so heterogeneous as the blood? We are acquainted with one agent that exerts such a power; namely, electricity: and this agent, as we formerly observed, seems to be employed by the animal economy for its operations, in the same manner, and on the same principles, as the materials themselves are employed, from which the animal body is constructed. Perhaps, therefore, the decomposition of the salt of the blood may be fairly referred to the immediate agency of this principle, electricity.* But here the question arises—What becomes of the soda from which the muriatic acid has been disunited? The soda remains behind, of course, in the blood, and a portion of it, no doubt, is requisite to preserve the weak alkaline condition essential to the fluidity of the blood. But the larger part of this soda is probably directed to the liver and enters with the bile the duodenum, where it is thus again brought into union with the acid which had been separated from the blood by the stomach. These observations illustrating the importance of common salt in the animal economy, seem to explain in a satisfactory manner that instinctive craving after this substance which is shown by all animals.†

Admitting that the decomposition of the salt of the blood is owing to the immediate agency of galvanism, we have in the principal digestive organs a kind of galvanic apparatus; of which the mucous membrane of the stomach and perhaps the mucous membrane of the intestinal canal generally, may be considered as the acid or positive pole, while the hepatic system may on the same view, be considered as the alkaline

* The most recent experiments support the view that lactic acid is the acid of the stomach, or of digestion. See Lehmann, Lehrb. d. Phys. Chem., Bd. 2.—G.

† It seems most probable that the demand for chloride of sodium relates to the blood, of which it is an essential constituent, and without which the globules of the blood could neither retain their form, nor perform their function.—G.

or negative pole. Whether such galvanic action be admitted or not, and the admission is of no very great importance, what we have above stated may be received as a simple expression of the facts in so far as they relate to the saline constituents of the blood. Besides, whatever be the nature of the energies by which these changes are effected, along with these changes and probably by the aid of the same energies other very important changes or processes are carried on, to some of which we shall presently have occasion to allude. In the mean time we may close this account of the preliminary function of the stomach, by noticing the strong grounds there are to believe that the solvent power we have described, or some power having a great resemblance to it, exists not only in the stomach but in every part of an animal body. In all animals there are minute tubes, called absorbents, which originate in every part of their bodies, and at length uniting, enter the sanguiferous system along with the chyle. Now the office of these tubes is to remove all the portions of the animal frame, which after having performed their several functions require to be withdrawn. Of course before solid parts can be thus removed, they must be dissolved (digested in fact); and such solution in many instances is probably effected as it is in digestion, by combining these solid parts with water. This supposed analogy between the solvent actions of the stomach and those actions which must prevail all over the body, seems to be strongly confirmed by the similarity of structure and of function existing between the lacteals and the absorbents; they indeed form but one system. We shall resume this subject in the next chapter.*

Secondly. *Of the powers of Conversion possessed by the Stomach.*—Though the proportions of the different ingredients of the chyle as ultimately formed are liable to be much varied according to the nature of the food, yet whatever the nature of the food may be, the general composition and character of the chyle remain always the same. The stomach must therefore be endowed with a power or faculty, the agency of which is to secure this uniform composition of the

* For some further particulars regarding digestion, the reader is referred to a Treatise on Stomach and Renal Diseases, by the author of the present volume. Book III. of the Fourth Edition.

chyle, by appropriate action upon such materials as circumstances may bring within its reach. Two indeed of the chief materials from which chyle is formed, namely the albuminous and the oleaginous elements, may be considered to be already fitted for the purposes of the animal economy without undergoing any essential change in their composition. But the saccharine class of alimentary substances, which form a very large part of the food of all animals except of those subsisting entirely on flesh, are by no means adapted for such speedy assimilation. Indeed one or more essential changes must take place in saccharine articles of diet, previously to their conversion either into the albuminous or into the oleaginous elements.

Most probably under ordinary circumstances these essential changes are altogether chemical; that is to say these changes are such as do take place, or rather such as would take place, if the primary elements of the substances thus changed in the stomach could, out of the body be so collocated, as to bring into action the affinities necessary for the changes produced in the stomach. Thus as we know, the proximate saccharine element spontaneously becomes alcohol, which as has been stated is merely an oleaginous body of a weak kind.* When therefore in the stomach it is requisite that sugar be converted into oil, it is probable that the sugar passes through precisely the same series of changes it undergoes out of the body, during its conversion into alcohol. We cannot trace the conversion of sugar into albumen, because we are ignorant of the relative composition and of the laws which regulate tho changes of these two substances. The origin of the azote in the albumen is likewise at present unknown to us; though in all ordinary cases, it seems to be appropriated from some external source. That the proximate oleaginous element may be converted into most if not into all the matters necessary for the existence of animal bodies, seems to be proved by the well-known fact

* M. Liebig has adopted this notion of the conversion of saccharine aliments into fat. M. Dumas, on the contrary, supposes that all fat found in animals is taken into the system as fat, with the food. We have no doubt of the accuracy of the opinions here advanced originally, and adopted by M. Liebig. (And which have been since fully confirmed.—G.)

that the life of an animal may be prolonged by the absorption of the oleaginous matter contained within its own body. Thus many hybernating animals when they retire in autumn to sleep during the winter, are enormously fat. But while they sleep their fat is gradually removed, till they awake in the spring quite divested of it and in a state of inanition.

The reader will have remarked that we have made use of the term extraordinary circumstances; and perhaps it may be right to explain what meaning we attach to that term.

When an animal is duly fed according to that diet which is natural to it, and for which its organization has been adapted, a regular and ordinary series of changes takes place within the animal, and the alimentary matters are converted into chyle. But one general characteristic of organized beings is, that within certain limits and for a certain time, they possess the power of varying their habits and of accommodating themselves to circumstances. Under extraordinary circumstances therefore, extraordinary changes must and do take place. In some instances, these changes out of the ordinary course are to an extent altogether astonishing, and such as defy our utmost calculation. The assimilating organs appear even to decompose elements which are still considered as primary, nay to form azote or carbon: so that it is impossible to define what on an emergency these organs are capable of doing. But what is thus done by these organs on an emergency, will usually be found to constitute an exception to what they do in ordinary; their ordinary mode of action being always that which is most simple, and which is thus to be considered as the rule. This extraordinary power of accommodation vested in organized beings, we consider to be necessary to their existence.

Thirdly. *Of the Organizing and Vitalizing Powers of the Stomach.*—In this part of our investigation, we meet the real difficulties we have to overcome in explaining the operations of living beings. The whole of the great and essential changes which alimentary substances undergo, may and perhaps will be traced by care and attention; but all beyond, will probably remain for ever unknown to us. Now at least, though we understand in some degree the chemical changes, of the vitalizing influence we in truth know absolutely

nothing. There is however every reason to believe that vitality is imparted through the agency of the living animal itself. For though from the natural composition of alimentary substances, they are to a certain extent fitted for the purposes of the animal economy, yet alone they are incapable of uniting themselves with the animal frame; and unless the living economy contribute likewise its share of the labour, the future work of assimilation will be incomplete.

Of the Changes the Food undergoes in the Duodenum.—We alluded in general terms to the bile and the pancreatic fluids, when we were treating of the organs by which these fluids are secreted. We have now to consider more particularly the nature of these secretions, and their share in the performance of the functions of the duodenum.

With the yellow colour and the intensely bitter taste of the bile all are familiar:—we need not therefore dwell on the sensible properties of the secretion, but proceed to notice its chemical composition. The chemical composition of the bile is very heterogeneous, though not perhaps so heterogeneous as has been represented; since it is probable that many of the ingredients said to be contained in the secretion, are products which have resulted from the methods employed in its analysis. Bile like all animal fluids is composed essentially of water; but the solid matters contained in the bile are nearly altogether formed from one or more proximate elements, in which carbon and hydrogen predominate. These proximate elements exist if not in conjunction, simultaneously with soda, with various salts of soda, and with other matters. The properties of the bile vary somewhat in different animals, but in all animals the peculiar characters of the bile remain wonderfully similar.

We are much less acquainted with the properties of the pancreatic fluid, than with the properties of the bile. The pancreatic fluid was formerly supposed to be of nearly the same composition as the saliva; but recent observations have shown that the pancreatic fluid contains albumen, and a curdy substance. The pancreatic fluid is for the most part in a slight degree acid, and holds in solution matters of a saline nature closely resembling those found in all animal fluids.

When the food which has undergone the first process of digestion in the stomach quits that organ and enters the duodenum, some other changes of a very remarkable kind take place. If the food originally contained no albuminous matter, no albumen is developed in the stomach; but immediately on the entrance of the semi-fluid mass into the duodenum, and its mixture with the bile and the pancreatic fluids, albuminous and other chylous matters become distinctly perceptible. At the same instant, those fluid parts which in the stomach were acid, are so far altered by the addition of the bile and the pancreatic fluids as to become neutral or almost neutral; some gas is frequently extricated, and that portion of the food which is destined to be excrementitious is evidently separated. The albumen which is thus found to exist in the chyme, may be partly derived from the pancreatic fluid, which as we have already mentioned has been said to contain albumen. But the quantity of albumen and of other proximate elements of the chyle that are found in the contents of the duodenum at some distance onward from the pylorus, is much too great to be explained in this manner. Indeed the properties as well as the quantity of the albuminous matters, show beyond a doubt, that the albuminous are developed from the food, and constitute the chyle which is subsequently taken up by the lacteals.

Such are those most interesting and at the same time most obvious phenomena observed in different animals, in which the changes produced on the food by the action of the duodenum have been examined. These phenomena appear to vary considerably according to the nature of the food; but so far as we can understand the phenomena, under every change of food the essential character of the changes which the food undergoes in the duodenum remains unaltered. That is to say, the acid formed in the stomach combines in the duodenum with the alkali of the bile, the albuminous elements are developed, and the excrementitious matters are more or less perfectly separated. Of the nature of the more recondite and vitalizing changes which take place in the duodenum, we are in the same state of complete ignorance as we are of the similar changes which take place in the stomach, and probably shall long so remain.

In the preceding account of the different processes which take place in the stomach and duodenum, and which are necessary for the conversion of the food of an animal into the living materials of its body, we have endeavoured to distinguish between what to a certain extent is within our powers of comprehension, and what is completely beyond them. It remains to be observed in conclusion, that though the three great and essential processes of digestion, namely the reducing, the converting, and the organizing processes are sufficiently distinct from each other, yet it is not to be understood that they take place in succession, or in the order in which they have been described. The fact is, all these processes go on at the same time; and as soon as a portion of food begins to be dissolved, its future changes seem to be determined. If it be necessary that the portion of food undergo an essential change, that change is accordingly begun. If no such change be required, the organising process itself begins simultaneously with the reducing process. The consequence of this union of the digestive process is as we have stated, that the staminal elements from which the living body derives its nourishment, are all developed in the chyle as soon as the excrementitious matters are separated by the biliary and pancreatic fluids.

Fourthly. *Of the Functions of the Alimentary Canal beyond the Duodenum.*—Compared with the functions of the stomach and duodenum, the functions of the succeeding portions of the alimentary canal as far as we can judge are unimportant. The digested mass passes from the duodenum into the jejunum and ilium; and before the food reaches the end of the ilium, the whole of the chyle contained in it has been absorbed into the apertures of the numerous tubes named lacteals.* These tubes open into the whole interior surface of the three portions of the alimentary canal, along which the food is moved from the stomach to the colon; but the lacteals are most numerous in those parts of the canal nearest to the stomach. From the ilium the undigested or excrementitious matters proceed into the cœcum; in which cavity in some animals as for example in the horse, even these excrementitious matters appear to undergo a second digestion; but in all animals the contents of the cœcum

* See Appendix.

have a very different aspect from the contents of any part of the alimentary canal nearer to the stomach. The mass of excrementitious matters continue their course from the cœcum into the colon, where they are still further changed. The nature of these changes however is not well understood, though they are probably of no small importance in the animal economy. Finally, all the nutritious portions of the food having entered into the system of the animal, nothing is left but what is entirely refuse.

Such is a short sketch of the phenomena of digestion and assimilation in so far as these processes are effected by the stomach and the alimentary canal. The phenomena suggest the following reflections:

1. With regard to the nature and the choice of aliments and the modes of their culinary preparation, it follows from the observations we have offered, that under similar circumstances, those articles of food which are the least organized must be the most difficult to be assimilated; consequently that the assimilation of crystallized or very pure substances must be more difficult than the assimilation of any others. Thus pure sugar, pure alcohol, and pure oil, are much less easy to be assimilated than articles of the saccharine class in the modified amylaceous form, or than that peculiar condition or mixture of alcohol existing in natural wines, or than butter. In these modified forms, the assimilation of the saccharine and the oleaginous elements is comparatively easy. Of all crystallized substances, pure sugar is perhaps the most easily assimilated; but every one is taught by experience that much less can be eaten of articles composed of sugar than of articles composed of amylaceous matter. In some varieties of the disease termed dyspepsia, the effect of pure sugar is most hurtful, perhaps fully as hurtful as the effect of pure alcohol. Nature has not furnished either pure sugar or pure starch; and these substances are always the results of artificial processes more or less elaborate, in which as in many of the processes of cookery man has been over-officious, and has studied the gratification of his palate rather than followed the dictates of his reason.

In many dyspeptic individuals the assimilating and preservative powers of the system are already so much weakened, as to be unable to resist crystallization within their

frames. Thus in gouty invalids, how often do we see chalk stones formed in every joint? Now with so little control over their own fluids, how can they reasonably hope to assimilate extraneous crystallizations? If therefore such an invalid, on sitting down to a luxurious modern banquet composed of sugar and oil and albumen in every state and combination except those best adapted for food, would pause a moment and ask himself the question, Is this debilitated and troublesome stomach of mine endowed with the alchemy requisite for the conversion of all these things into wholesome flesh and blood? He would probably adopt a simpler repast, and would thus save himself from much uneasiness. The truth is, many of the elaborate dishes of our ingenious continental neighbours are scarcely nutritious or designed to be so. They are mere vehicles for different stimuli—different ways in short of gratifying that low animal propensity by which so many are urged to the use of ardent spirits or of various narcotics. In one respect indeed, namely in reducing to a state of pulp those refractory substances which we have before mentioned, the culinary processes of our neighbours are much superior to ours; but in nearly every other respect, and most of all in the general use of pure sugar and pure oil, their cookery is eminently injurious to all persons who have weak digestion. On the other hand, in this country we do not in general pay sufficient attention to the reducing processes of the culinary art. Everything is firm and crude, and though the mode of preparation be less captivating, the quantity of indigestible aliment is quite as great in our culinary productions as in those of France.

We are not however writing a treatise on cookery or dietetics, but in treating of the function of digestion it is impossible altogether to omit these important subjects. The foregoing observations are merely intended as illustrations of those general means which often regulate the choice and the preparation of the food of mankind, in a state of civilized society. Reason is too little followed, the indulgence of the palate is the sole object; so that the organs of digestion already enfeebled and incapacitated for the assimilation even of the most proper nourishment, are daily oppressed with a task for which they are altogether

unequal. The consequence is, that though for a time the labour be sustained, the digestive energies are at length overcome. The dyspeptic being passes half his days in misery; his offspring inherit their parents' constitution; and if they persist in a like course of slow poison, after a few generations the race becomes extinct,—"his name even is cut off from among men!" Providence has gifted man with reason: to his reason therefore is left the choice of his food and drink, and not to instinct as among the lower animals; it thus becomes his duty to apply his reason to the regulation of his diet, to shun excess in quantity and what is noxious in quality, to adhere in short to the simple and the natural, among which the bounty of his Maker has afforded him an ample selection, and beyond which if he deviates, sooner or later he will suffer the penalty.

2. The view we have now taken of the processes of digestion, removes in some degree that mysterious character with which they have been invested; and by lessening the field of our inquiry brings us nearer to our object. We had previously known that the articles employed as food by animals, are essentially compounds of three or four primary elements. But we have now learnt that all the more perfect of those matters on which animals subsist, are compounds of three or four proximate elements; the whole of which compounds except one (the saccharine,) are in their essential characters identical with the materials composing the frame of the animals themselves. We have also learnt that owing to this identity of composition, many animals are saved the labour of forming these constituents of their frame from the primary elements, and have only to re-arrange the proximate elements as their exigencies may require. The task of elaborating the proximate elements is thus left to the inferior animals or to plants; which are endowed with the capacity of compounding these proximate elements from things still lower in the scale of organization than the animals and plants themselves. Hence there is a series, from the lowest being that derives its nourishment from carbon and carbonic acid, up to the most perfect animal existing. Each individual in the series preferring to assimilate other individuals immediately below itself; but having on extraordinary occasions and in a minor degree, the

power of assimilating all, not only below but above itself in the system of organized creation.

3. We stated that the immediate influence employed by the organic agent is probably galvanism, or the common agents operating throughout inorganic matter; and that the digestive apparatus viewed as a whole, seems to be arranged on galvanic principles. We wish however our readers clearly to understand, that we consider the organic agent residing in the ganglionic system of nerves and employing the electric agency, to be not electricity itself, though the ganglionic agency is probably the lowest kind of agency existing in animal bodies, and only as it were one degree above the agencies of inanimate matter. We dwell on this point the more, because from deficient recollection of what electricity is, and what are the living powers acting through the nervous system of animals, it has been maintained, nay has even been endeavoured to be experimentally proved, that these nervous powers are identical with the powers of electricity. It is impossible to imagine a greater fallacy. Admitting that electricity properly directed could change the proximate elements of the food into the proximate elements of chyle, can we imagine electricity to vary spontaneously its mode of operation, so as to produce the same chyle from every sort of aliment—that electricity is an intelligent agency acting with a certain object? Besides if the nervous energy be identical with electricity in one set of nerves, the energy of all nerves must be more or less identical with electricity: for though powers of a higher order may be imagined to reside in different classes of nerves, the whole nervous system must be supposed to possess in common, certain other powers analogous to, if not identical with the inferior power residing in the ganglionic nerves; otherwise that free communication so plainly indicated by the general structure of the nerves, could not be supposed to take place among the different parts of the nervous system. Now on the supposition that the inferior power residing in the nervous system is identical with electricity, how different must be the functions of that agency in the different classes of nerves; in one class of nerves for example, digesting and assimilating the food; in another class helping to convey sight or sound; in the

brain itself, shall we say, actually thinking, or at least conveying thought! As to the experiments on which it has been attempted to rear this most untenable opinion, they prove nothing whatever, and are easily explained on other grounds. Such explanation would be foreign to our present object were we to introduce it here. But there is one observation which has always appeared to us conclusive against this fancied identity of the nervous energy with electricity, and with which we shall close the present chapter.

Most persons are aware that there are certain fishes endowed with the power of evolving electricity, and of communicating a smart shock to other animals. Now in all the fishes in which this power resides as in the Torpedo, there is a complicated apparatus extending over a large portion of the fish's body, expressly for the purpose of forming the electricity which the fish communicates; thus proving beyond a doubt that mere nerves are not sufficient to develope electricity, and that when electricity is wanted, an express and peculiar organ is as requisite for its secretion or formation, as for the secretion and formation of any other product of the animal economy.

The further reflections suggested by the facts we have now detailed, will be given in conjunction with the reflections suggested by the facts to be detailed in the next chapter.

CH. IV. — OF THE PROCESSES OF ASSIMILATION SUBSEQUENT TO THOSE PROCESSES WHICH THE FOOD UNDERGOES IN THE STOMACH AND ALIMENTARY CANAL; PARTICULARLY OF THE CONVERSION OF THE CHYLE INTO BLOOD. OF THE HEPATIC FUNCTION. OF RESPIRATION AND ITS USES. OF SECRETION. OF THE FINAL DECOMPOSITION OF ORGANIZED BODIES. GENERAL REFLECTIONS, AND CONCLUSION.

First. *Of the Passage of the Chyle from the Alimentary Canal into the Sanguiferous System; and of the Function of Absorption generally.*—The Chyle as we have already said, is taken up from the alimentary canal by numerous minute tubes named lacteals; these tubes being part of the system of similar tubes which arise from all parts of the

body and are termed absorbents. The whole of the absorbing tubes after passing through various glands, at length unite into one or two of larger size; the recipient tube on the left side being by far the largest, and known by the appellation of the thoracic duct. These larger absorbent tubes pour their contained fluids into the veins named the sub-clavian, and thus into the general mass of the blood. The exact nature of the changes which the chyle and the lymph undergo in their passage through these tubes, is not well understood. One change appears to be, that the chyle first formed in the alimentary canal, is to a certain extent completed or freed from water during its course through the lacteals; for though when the chyle is mixed with the blood, its albuminous elements are much less perfectly developed than those contained in the blood itself, yet the developement of the albuminous elements on their mixture with the blood is more perfect than when the chyle is first taken up from the alimentary canal.

The matters conveyed from the other parts of the body by the tubes of the general absorbent system, have by most physiologists been supposed to be of an excrementitious character. That some of the absorbed matters are excrementitious is very probable; arguments may however be adduced to show that the whole of the matters absorbed are by no means excrementitious, but that they are repeatedly consigned to the uses of the vital agency; every new organization raising them as it were a step higher, and qualifying them for those refined and ulterior purposes, for which we can hardly imagine the crude chyle to be at once adapted.

The circumstances favouring the above opinion, which we are now desirous to mention, are,—

1. It is unreasonable and contrary to every thing we know respecting the operations of the animal economy, to suppose that the chyle should be separated from one kind of excrementitious matter in the alimentary canal, in order to be immediately mixed again with other excrementitious matters in the chyliferous tubes. It is therefore a just inference, that if the matters contained in the absorbents were really and wholly excrementitious, they would be carefully kept apart, and would be removed from the system

by some other means than by tubes united with the tubes conveying the nutritious fluids.

2. By admitting that the fluids contained in the absorbent tubes possess a highly animalized character, the design of their union with the crude and imperfectly animalized chyle becomes apparent; the fluid in the absorbents will be seen to execute an important and necessary office by raising the vital character of the chyle, and qualifying it for becoming a part of the general mass of the blood. We thus obtain a cogent reason why the fluids taken up from the internal surface of the alimentary canal should be mingled with the fluids absorbed from the other parts of the body; a mixture which is inexplicable on the hypothesis that the fluids in the absorbent tubes are wholly excrementitious.

3. The gradual developement of the proximate elements of animal bodies by repeated organizing processes, fully accords with those general views of the operations of nature which throughout this work we have endeavoured to illustrate; and which lead to the general conclusion that the operations of nature are never abrupt, but always slow and gradual. Further it is more reasonable to conceive that matters already assimilated to the animal body, are better fitted for its immediate uses, than matters which like the chyle, have only received an imperfect assimilation.

4. Many animals can and do live for a considerable time, on substances contained in their own bodies. Thus hybernating animals as previously stated, have the ability to assimilate further those matters which have already become part of themselves; consequently such a faculty of progressive organization as we have supposed, actually exists; and a sort of digestion is carried on in all parts of the body, to fit for absorption and future appropriation those matters which have been already assimilated. Were it necessary, other arguments to the same effect might be added; but we shall at present delay the further consideration of the assimilating character of the whole absorbent system, that we may recur to it again in a succeeding part of the present chapter.

Secondly. *Of the Blood.*—The blood is that well-known fluid pervading the tubes named from their function the blood vessels; which tubes are extended more or less over

every part of an animal. We have already described the general distribution of the blood vessels, and shall now confine ourselves chiefly to the properties of the blood itself.

The chyle as we have stated, is poured into the general mass of the blood near the heart; and from the heart is almost immediately propelled through the lungs. The chyle thus set in motion, is not only united thoroughly with the blood, but undergoes those other important changes, by which its final conversion into blood is accomplished. The exact nature of these changes is unknown; but they are evidently of a completing character—that is to say, the weak hydrated ingredients of the chyle are freed from a portion of the water with which they were associated, and are transmuted into the strong albuminous substance of the blood.

The chief constituents of the blood are essentially albuminous. Blood contains albumen in three states of modification, namely albumen properly so called, fibrin, and the red particles. In addition there are oily matters; besides various minute portions of other animal matters, and saline matters, all dissolved or rather suspended in a large quantity of water. The following short table exhibits the relative proportions of the constituents of human blood to each other, as they exist in most individuals.

ONE THOUSAND PARTS OF HUMAN BLOOD CONTAIN

Of Water	783·37
Fibrin	2·83
Albumen	67·25
Colouring matters (of which six per cent are iron)	126·31
Fatty matters, in various states	5·16
Various undefined animal matters, and salts	15·08
	1000·00*

The reader will not fail to remark that among these constituents of the blood, gelatine is not mentioned. In fact, though existing most abundantly in various animal structures, gelatine is never found in the blood, or in any product of glandular secretion. We formerly noticed that in the scale of organized substances, gelatine appears to rank

* Le Canu; mean of two analyses.

lower than albumen; and we may now add that a given weight of gelatine contains at least three or four per cent. less carbon, than an equal weight of albumen. The production of gelatine from albumen must therefore be a reducing process. We shall presently have occasion to revert to these facts. In the mean time we subjoin the few observations we have to offer on the organization or structure of the blood.

The organization of the blood is even more wonderful than its chemical composition, and is still less understood. The red portion of the blood for example is composed of innumerable minute globules or rather discs, varying in size in different animals, and in all instances highly organized; the real structure indeed of these globules is imperfectly known; they were formerly supposed to consist of solid colourless nuclei within red vesicles; but the general opinion as we have just stated, now is that they are flattened discs with a depression in the centre,* which by an optical deception under the microscope assumes the form of a solid colourless nucleus. The fibrin and oily matters also are diffused through the mass of the blood in a state of equally minute subdivision. The particles of the fibrin are colourless, and their magnitude much less than the magnitude of the red particles. The particles of oily matter are also colourless, but of variable magnitude.

During the life of an animal, the particles of the fibrin as well as the red particles of its blood, seem to be in a state of extreme self-repulsion: by which self-repulsion the union of these particles is prevented, except as the economy of the animal may require and may determine. After death however or in blood withdrawn from the body of a living animal, the property of self-repulsion more especially among the fibrinous particles of the blood, ceases, and they readily cohere; this cohesion is termed the coagulation of the blood. Much beautiful design is probably concealed under that peculiar organization of the blood, to which it owes its coagulating tendency. One result of the coagulation of the blood indeed is as obvious as it is important, namely the prevention of hæmorrhage. If the blood did not coagulate, the existence of animals would be most

* There is now no doubt about the truth of this statement.—G.

precarious, as on the slightest injury they would be liable to bleed to death.

Thirdly. *Of the Hepatic Function.*—In a former chapter we gave a short account of the liver, and of the peculiarities of its circulation. Here it will be therefore necessary only to remind the reader, that the venous blood from the digestive organs undergoes an arterializing process in the liver before it enters the sanguiferous system; and that the bile eliminated by the liver enters the duodenum at a certain stage of the assimilative processes, when it contributes to the formation of the chyle.

At the beginning of the present chapter, we alluded to the vessels termed lacteals and absorbents. These vessels together constitute an apparatus supplementary to the sanguiferous system, and their office is to absorb or take up nutritious matters in advanced stages of assimilation; which matters after some further processes, are fitted for admixture with the general mass of blood, and for undergoing with that fluid the important changes produced by its exposure to the air in the lungs. Now it has been distinctly ascertained that veins, particularly in their extreme ramifications, possess a power of absorption somewhat analogous to the power of the lacteals and absorbents. Venous absorption however, appears to be of a more general and indiscriminate character than the absorption by lacteals and absorbents; hence many matters are readily taken up by veins, which would probably be rejected by absorbents. Thus after the reduction of the alimentary substances to chyme, and its passage from the stomach into the duodenum, the lacteals absorb only the assimilated chyle; while much of the remainder of the chyme, consisting chiefly of saccharine and oleaginous articles partially assimilated, seems to be taken up by the veins of the intestines. These imperfectly assimilated matters thus mixed with the venous blood, (already deteriorated by the previous assimilating processes,) form principally the crude menstruum from which the bile is eliminated by the liver. The bile thus separated is retained in the gall-bladder or in the liver itself till it is required; and then as we have stated, is discharged into the duodenum, where it is brought in union with the chyme from the stomach. By this union of the bile with the chyme,

the albuminous chyle fitted for lacteal absorption is distinctly separated; while part of the remaining bile in some unknown state of combination with the partially assimilated saccharine and oleaginous elements, is as we have said, absorbed by the veins, and the residuary and smaller part is rejected as excrementitious.

Numerous observations lead us to infer that during the hepatic process above described, a portion of the saccharine and oleaginous aliments becomes associated with azote, and forms an albuminous or some nearly allied principle; while the remaining and perhaps the greater portion of those aliments is converted into fat, to be either employed for immediate use or stored up for the future wants of the economy, as circumstances may determine.*

The reader will remember that the bile like the saccharine and oleaginous aliments, is distinguished by the absence of azote, and by the relatively large proportion of carbon it contains. The liver therefore according to the preceding views, is the great appropriator and assimilator of carbon.

This subject will be resumed after we have considered respiration.

Fourthly. *Of the Pulmonary Function. Respiration.*—The function of Respiration or breathing, is perhaps the most indispensable in the animal economy: many of the other functions may be interrupted, but the suspension of breathing is immediately destructive of life. When we describe the phenomena of the circulation of the blood, we observe that the blood in passing through the lungs is exposed to the action of the atmospheric air. Now during this exposure of the blood to the atmospheric air, it undergoes certain changes. The blood from the right side of the heart, when it enters the lungs is of a dark red colour; the blood is then dispersed in a state of most minute subdivision through the ultimate vessels of the lungs, and in these vessels is brought into contact with the atmospheric air, when it becomes of a bright red colour. In other words, the blood changes in the lungs its venous appearance, and assumes the character of arterial blood. The blood thus arterialized returns to the left side of the heart, and from the left side of the heart is propelled through the whole arteries of the

* See Appendix.

body. In the minute terminations of the arteries, the blood again loses its florid hue, and reassuming its dark red colour is returned through the veins to the right side of the heart, to be exposed as before to the influence of the atmospheric air and to undergo the same succession of changes.

On examining the respired air, a remarkable alteration of its properties is found to have taken place; a portion of its oxygen has disappeared, and a nearly similar bulk of carbonic acid gas has been substituted. With respect to the origin of this carbonic acid gas, there have been various opinions. Formerly the great number of physiologists maintained that carbon in some form was excreted by the lungs; and that this excreted carbon uniting with the oxygen of the inspired air, was converted into carbonic acid gas. No one imagined that oxygen gas could be passing inwards through the membrane of the lungs, while carbonic acid gas was at the same time passing outwards through the same membrane. Accurate observations have however demonstrated, that such a simultaneous passage of gases really take place through the membrane of the lungs; and the observations are not confined to the two gaseous bodies in the lungs, but are applicable to all gases whatever under similar circumstances. In consequence of these observations, it seems now to be generally admitted that the oxygen of the atmospheric air is absorbed by the blood, more especially by the red particles, and in some unknown state of combination, reaches the extreme subdivisions of the arteries; where being united with a portion of carbon and hydrogen, it forms carbonic acid gas and water; that this carbonic acid is retained in some unknown state of combination in the venous blood, till in the lungs it is expelled, and oxygen is absorbed in its stead, according to the laws which regulate the diffusion of gaseous bodies and which were formerly explained. Along with the carbonic acid gas, a large quantity of aqueous vapour as we have stated is at the same time separated from the blood.

It would be foreign to the objects of this treatise, were we to enter further into the reasons for the view we have given of the phenomena of respiration. These reasons are many and strong, and seem indeed to prove clearly that the changes which the blood undergoes during its circulation

through the body, are as we have described them. We shall therefore assume that our view of respiration is correct, and shall offer a few remarks on the attendant circumstances and on the consequences of respiration.

1. To what influence are we to ascribe the different colours of arterial and of venous blood? The opinion formerly held was that the arterial colour arose from the absorption of oxygen, and the venous colour from the presence of carbon. But recent observations seem to show that the change in the colour of the blood during its circulation, if not entirely independent of oxygen, is much influenced by the saline matters; particularly by the common salt which the blood contains, and that the dark colour of venous blood is principally owing to the presence of carbonic acid gas.

2. What is the source of the carbonic acid in venous blood, and of the aqueous vapour which is expelled from the lungs? These questions cannot be answered with certainty. But some observations lately made have induced us to believe, that the conversion of certain forms of albuminous matters into gelatine is one source of the carbonic acid in venous blood. Gelatine as before stated, contains three or four per cent. less of carbon than albumen contains. Now gelatine enters into the structure of every part of the animal frame, and especially of the skin, the skin indeed consists of little else besides gelatine; it is most probable therefore that a large part of the carbonic acid of venous blood is formed in the skin, and in the analogous textures. Indeed we know that the skin of many animals gives off carbonic acid and absorbs oxygen, in other words performs all the offices of the lungs, a function of the skin perfectly intelligible on the supposition that near the surface of the body, the albuminous portions of the blood are converted into gelatine. With respect to the aqueous vapour thrown off from the lungs, we have every reason to believe as before stated, that much of this vapour is derived from the chyle in its passage through the lungs; and that by such separation of water, the weak and delicate albumen of the chyle is converted into the strong and perfect albumen of the blood, according to the principles detailed at the commencement of this chapter.

3. What are the uses of the continual extrication of car-

bonic acid from living animals, and could not a little superfluous carbon have been thrown off from their bodies in a more simple manner? The precise use of the constant evolution of carbonic acid, or how is it effected, we know not; but one great use which has been assigned to this evolution, is the formation of the heat of the body; and not only the power of forming that heat, but also the power of varying it according to circumstances—a power so characteristic of organic life. Out of the body, carbon and hydrogen certainly give off heat on combination with oxygen. Hence it has been maintained with great plausibility, that the same combinations within a living body may give origin to its heat; though it must be confessed, there are some difficulties about this view of the origin of animal heat which detract considerably from its likelihood. Moreover it is exceedingly probable that though the evolution of carbonic acid gas and water may be one of the means possessed by the animal economy for generating heat, there are yet other means the nature of which at present is quite unknown.

The quantity of carbon thrown off by the lungs, is very abundant, but has probably been much overrated. Philosophers formerly estimated that the lungs of a man of ordinary size expel, in the course of twenty-four hours, about 11 ounces of carbon; but M. Liebig has recently estimated the quantity of carbon daily taken by a man in his food, and expelled from the lungs as carbonic acid gas, at no less than 13·9 ounces! This celebrated chemist also, in adopting the views above given respecting the source of animal heat, has pushed them much further, and maintains that animal heat is entirely the result of the union of the hydrogen and carbon in the system with oxygen, and that the chief use of nonazotized articles of food, i.e. of saccharine and oleaginous aliments, is to furnish carbon and hydrogen for combustion and for the maintenance of animal heat! We have already said and with many others always admitted, that the union of oxygen with carbon and hydrogen is one source of animal heat; but at present we totally dissent from the opinion that such union of oxygen with carbon and hydrogen is the only source of animal heat, or that the only use of saccharine and oleaginous aliments is that assigned.*

* We had intended to state some objections to these assumptions,

The subjects of Respiration and Animal Heat, notwithstanding the attention they have received from physiologists, are we think very imperfectly understood; and if we are not mistaken, these important functions will hereafter be placed in an altogether different light from that in which they are at present contemplated.

Fifthly. *Of Secretion.*—From the blood are formed by means of peculiar apparatus, all those numerous products termed Secretions; not only so unlike each other, but so unlike the fluid from which they are separated. Some of these secreted products appear to be little else than a disengagement of certain matters already existing in the blood. Other secretions have no resemblance to any ingredient of the blood; consequently in the glandular structure, by which these secretions so dissimilar to the blood are formed, the blood must undergo some essential change. In the present state of our information however, we must content ourselves with a limited insight into the nature and the causes of secretory action. We see that secreted products are of two kinds: that some of the matters separated by animal bodies are evidently thrown off on account of their noxious qualities, are in fact excretions, which could not be retained without proving fatal to the life of the animal from which they are detached; while other matters separated from animal bodies are as evidently intended for further objects, and for the performance of various subordinate actions in the living system, are in fact secretions properly so called. But as we have stated, we are still perfectly unacquainted with the intimate nature of the changes which produce the secreted fluids; though it is probable that a careful examination of the phenomena would throw much light on the general character of these changes, and would display evidence of the most consummate design.

Sixthly. *Spontaneous Decay of Organized Bodies.*—It remains to conclude this chapter with a brief notice of the spontaneous and inevitable decay that awaits all the

but have thought it better to refer the reader to a treatise on the Statics of the Human Chest, Animal Heat, &c., by Julius Jeffreys, Esq., where some arguments will be found against them, which appear to us unanswerable.

things produced by organization, after they have been removed from the influence of those organic agents, by which the combination of their constituent elements was effected.

The organized beings that inhabit this globe, however, numerous, are very few in comparison with the magnitude of the globe, and seem to occupy its surface only. We have seen that the elements forming the structure of organized beings are not only combined in different proportions, but that in many instances these elements appear to undergo further decomposition into ultimate forms of matter, which out of a living body do not, and perhaps in the present constitution of the universe cannot exist in an isolated state. Owing to this diversity in the composition of organized beings from the composition of inorganic matter, and to other causes which will readily occur to the reader, organized beings and their laws are in continual opposition to the general laws by which inorganic matter is governed. To counteract therefore these opposite laws, and to maintain the existence of organized beings, demands the unremitting efforts of the organic agency. But at length these efforts are exhausted, the contest ceases; when the general laws of inorganic nature prevail, and speedily reduce to their original state of existence, the atoms which had been incarcerated in the living frame.

The spontaneous decay of organized beings is usually termed the putrefactive process; and some substances have much more tendency than others to undergo putrefaction. As might be expected, substances whose composition is most simple, as the oils and articles of a like nature, are also the most permanent; while substances more compounded, especially those substances which include azote, are exceedingly liable to putrescent change. For such changes a certain degree of heat and of moisture appear to be necessary; since at a temperature below the freezing point of water or in a perfectly dry state of the atmosphere, even animal substances may be preserved unaltered during any length of time.

The phenomena resulting from the dissolution of different kinds of organized matters are of course different; but in every instance the tendency is toward the formation of

compounds more simple than the matter decomposed; that is to say, of compounds whose existence out of a living body is not incompatible with the present state of the globe. The matters which in a warm and damp air seem first to be loosened from organic combination, are those foreign bodies we have already mentioned as existing incidentally in every part of the structure of organized beings, in some unknown but active self-repulsive state. Hence arises during putrescence the formation of sulphuretted and phosphuretted hydrogen, and of other undefined compounds of the same elements; and these gaseous compounds chiefly produce the very offensive odour of putrefaction. At the same time there are formed carburetted hydrogen, oil, acetic acid, ammonia, and last of all carbonic acid gas and water, while the azote is extricated in a gaseous condition. Finally both vegetable and animal matters, but vegetable matters more especially, are reduced to the state of mould. The mould from vegetable matters consists principally of carbon in combination with a little oxygen or hydrogen; the mould from animal bodies contains the same elements as vegetable mould, together with a little azote and the usual saline ingredients of organized substances. In this form of mould the remains of vegetables and of animals as was before stated, constitute the food of plants. By plants these remains are organized, and thus go through the same series of changes.

We may here pause for a moment, and on account of the general reader, briefly recapitulate the most striking facts, which have been detailed in the present, and in the preceding chapters.

In the first place, the mechanical arrangements for reducing the food of animals to the proper degree of comminution are wonderfully varied, according to the peculiar qualities of that food. In the graminivorous and granivorous tribes for example, the teeth are literally instruments for grinding or triturating herbaceous matters and seeds. In carnivorous animals such a structure would be useless; the teeth therefore are suited only for cutting or tearing. In gnawing animals the teeth present a totally different structure, but at the same time are admirably fitted to the habits of the animal. Occasionally as in the fowl tribe of

birds, the grinding apparatus is placed not in the mouth but in the stomach itself; this organ being as it were expressly contrived for trituration; while some of tho functions the stomach performs in other animals are transferred to contiguous parts.

The structure and mechanism of the stomach and of the alimentary canal then claimed our particular attention. In carnivorous animals, whose food requires comparatively little assimilation, the alimentary canal is short and of a simple structure. On the other hand in vegetable feeders, that canal is long and complicated; but perfectly adapted for maccrating their food, and for extracting from it, every thing that can be converted into nourishment. Nor is there an adherence to any model, but the whole alimentary structure is throughout varied; as if in order to demonstrate the power and the wisdom of Him, by whom the organization of animals has been contrived. The alimentary canals of the cow and of the horse are formed on entirely different models, though the food of both animals is nearly the same.

We proceeded in the next place, to the consideration of the chemical changes which the food undergoes in the stomach and duodenum. In these changes we discover arrangements not less wonderful, indeed more wonderful, than in the arrangements of structure and of mechanism. The variety of forms assumed by bodies having the same essential composition, produce a latitude in the choice of diet, which is almost infinite; at the same time, the organs being endowed with the power to discriminate all the differences, and to act on the primary elements of bodies, elaborate the same uniform chyle from every variety of food. The power by which the stomach is enabled to effect these astonishing changes, is the power which it possesses of associating the different alimentary substances with water; the power in short of dissolving or digesting them. This dissolving power seems to be exerted by the stomach through the agency of chlorine derived from the common salt in the blood; at least chlorine is always present in the stomach during the act of the solution of the food, though the precise mode in which the chlorine operates is still unknown. Contemporaneously with the act of solution of

the food, such essential changes take place in its composition as are requisite for perfecting the future chyle.

The stomach having accomplished its office, the digested mass enters the duodenum; where the series of changes is continued in a manner equally wonderful. In the duodenum, the digested mass is brought in contact with the biliary and the pancreatic fluids. The alkali of the bile unites with the acid, with which the food had been mingled during its digestion in the stomach; the excrementitious parts both of the food and of the bile, are separated or precipitated; while at the same time, the peculiar proximate constituents of the chyle are eliminated in a condition appropriate for their absorption by the lacteals.

There are two divisions of those minute tubes composing what is termed the absorbent system of animals;—the lacteals—and the absorbents properly so called. The ultimate ramifications of the lacteals originate from the internal surface of the alimentary canal, where they take up the digested and partly assimilated aliment or chyle. The ultimate ramifications of the proper absorbents originate from all parts of the body; and are enabled to take up by some peculiar process, every component of the body, solid as well as fluid, in the same manner as the chyle is taken up by the lacteals.

The fluid obtained from the lacteals, and the fluid from the proper absorbents, are both alike albuminous. The albumen of the chyle, as we have formerly shown, is produced in the stomach and duodenum, while the food is undergoing the process of digestion. But whence is derived the albumen found in the proper absorbents? The animal body we know to be composed of a great variety of matters, among which gelatine predominates. Now since albumen only is found in the absorbents, it follows that the gelatine of the body previously to its being taken up by the absorbents, is reconverted into albumen; in other words, the absorbed gelatine undergoes a process entirely analogous to that process which gelatine and other matters undergo in the stomach and duodenum, during the process of digestion. Hence the digestive process, instead of being confined to the stomach and duodenum, is actually carried on without intermission, in all parts of a living animal body.

The two kinds of fluid albumen derived from these two sources, that is to say the crude chyle in the lacteals aud the highly animalized lymph in the absorbents, are at length commingled, and form one uniform fluid of an intermediate character, adapted for becoming a part of the general mass of the blood. The character however of this fluid when it becomes part of the blood, though albuminous, is still very weak: that is to say, the commingled fluid from the lacteals and from the absorbents consists of albumen, holding a large proportion of water in a state of essential combination. By a beautiful arrangemeut, as soon as this weak albuminous fluid has joined the stream of blood, it is hurried through the lungs, where it undergoes a remarkable change. In the lungs, the water which we have shown to be in essential union with the weak albuminous matter of the chyle, is separated from that state of union, and is expelled along with the carbonic acid gas which is continually escaping from the lungs; the weak and delicate albuminous matter of the chyle is thus converted into the strong and firm albuminous matter of the blood. We are next brought to consider the process of respiration.

The blood in its course through the lungs emits carbonic acid gas, and assumes a florid arterial colour. In the lungs, the blood also, according to the principles of gaseous diffusion, absorbs a portion of oxygen from the air of the atmosphere. The oxygen thus absorbed remains in some peculiar state of union with the blood [Query, as oxygenated water, or some analogous compound ?] till the blood reaches the ultimate terminations of the arteries. In these minute tubes the oxygen changes its mode of union; the oxygen is converted into carbonic acid by combining with a portion of carbon derived from the albuminous principles of the blood; at the same time heat is extricated. Two distinct alterations take place during the union of the carbon with the oxygen in the ultimate terminations of the arteries: First, a portion of an albuminous principle contained in the blood is supposed to be reduced to the state of gelatine, to be appropriated toward the renovation of gelatinous textures. Secondly, the carbonic acid formed from the albuminous and perhaps other matters, unites with the blood, communicates to the blood its dark venous colour,

and is transferred to the lungs. By the lungs the carbonic acid is expelled from the system, along with a portion of aqueous vapour derived principally from the weak albumen of the chyle, as formerly explained.

The blood is the source not only of all the constituent parts of animal bodies, but likewise of all the various secretions; many of which secretions differ altogether in their properties from the properties of the primary fluids, and perform secondary offices of great importance in the animal economy. Other products separated from the blood are purely excretions; as for instance the carbonic acid gas from the lungs, which could not be retained in the animal system without destroying life.

Finally, the life of the animal becoming extinct, the essential properties of the matter of which it is composed resume their natural action, and speedily restore the elements to their original condition.

Such is a summary of the operations of living bodies, which in the present and in the preceding chapters we have endeavoured to illustrate. Our insight into these operations, though very imperfect, is amply sufficient to satisfy us of the infinite wisdom by which they are directed; and that the unknown must be far more wonderful than what has been disclosed. Most of the facts also on which we have dwelt, are of a character so obvious that they require only to be understood in order to be admitted among the proofs of the great argument of design; at least, by all but persons who affect to deny that argument. We therefore leave to the reader the application of facts so clearly demonstrative of design, and proceed to offer a few considerations regarding certain general arrangements of organized and living beings, relatively to the arrangements of inorganic matter.

First. In viewing the economy of organized beings, one of the circumstances most calculated to arrest our attention, is the extraordinary skill manifested in the disposal of the various parts of the organized system with regard to each other. As an instance on the great scale, may be noticed the mutual relation and dependence of plants and animals.

The following table, stating the general contrast between

plants and animals, has been recently published by MM. Dumas and Cahours.*

VEGETABLES	ANIMALS
Produce neutral azotized substances;	*Consume* neutral azotized substances;
——— fatty substances;	——— fatty substances;
——— sugar, starch, and gum;	——— sugar, starch, and gum;
Decompose carbonic acid;	*Produce* carbonic acid;
——— water;	——— water;
——— ammoniacal salts;	——— ammoniacal salts;
Disengage oxygen;	*Absorb* oxygen;
Absorb heat and electricity;	*Produce* heat and electricity;
Reduce oxidized bodies;	*Oxidize* bodies;
Are *stationary.*	Are *locomotive.*

This table doubtless presents a contrasted outline of the general relation of vegetable and animal existence, yet like many other comprehensive expressions, will scarcely admit of literal application in individual cases. The truth is, that so far from vegetables and animals being separate and distinct existences, animals may be said in certain respects to include vegetables; that is to say, in animal bodies an apparatus exists in some measure corresponding to the vegetable apparatus, which not only appropriates and further assimilates albuminous (*i.e.* azotized) oleaginous and saccharine matters, but is even capable within certain limits of producing from more simple materials, as well as from one another, these three great classes of proximate elements. This apparatus in animals as we formerly mentioned, is the hepatic apparatus; which seems to be analogous in many of its functions to the Phyllic or leaf-function of plants. The leaves of plants as we have stated appropriate the carbon from carbonic acid existing in the atmosphere, and liberate the oxygen. The liver in animals appropriates saccharine and oleaginous matters, remarkable for the predominance of carbon in their composition. Besides the analogy between the colour and other sensible properties of the phyllic and hepatic secretions, many other circumstances might be mentioned in favour of their analogy, which it would be foreign to our present purpose to detail. Taking for granted this analogy between the phyllic and hepatic

* Annales de Chimie et de Physique, tom. vi. p. 385. Third Series.

functions, we see in it a wise provision against sudden emergencies arising from the temporary absence or deficiency of proper food, and without which provision animal existence would become impossible or extremely precarious.

Again what is said of plants absorbing, while animals give out heat and electricity, is not to be understood in a literal sense; since it is well known that many plants are capable of maintaining a certain temperature above that of the surrounding atmosphere, and thus possess in a limited degree the faculty of resisting frost. Similar remarks might be made with respect to most of the other contrasts in the table. In short as we have said, so far from plants and animals being distinct and separate organizations, they both possess certain faculties in common; and animals in particular may be said in a manner to include vegetables.

Notwithstanding however, a community of organization and of function, there is no doubt that on the great scale of nature, a certain mutual relation and dependence exist between plants and animals. Thus carbonic acid gas is the main support of vegetable life, while nearly the whole of the superfluous carbon produced by the operations within animal bodies, is actually thrown off in the form of carbonic acid. Plants therefore on the one hand supply the chief nourishment to animals, while that gaseous matter which is separated by the animal economy, and which if retained within animals would to them be fatal, constitutes on the other hand the chief food of plants. Nor in these two respects only, are the two great systems of organization mutually dependent; for unless plants consumed the carbonic acid gas which is formed by animals, this deleterious compound would probably accumulate in the atmosphere so as to destroy animal life; while it is doubtful whether the present races of vegetables could exist if carbonic acid gas were not formed by animals.

Besides, the general scheme of Providence for the nourishment of animals claims our especial notice. Animals have not only been destined to prey on each other; but all created beings are the food of other beings progressively higher than themselves in the scale of organization. By this arrangement, the labour of the assimilating power has been greatly diminished; and by the same means, that

accumulation of dead animal remains which soon would be overwhelming, is entirely prevented. Even in the fabric of individual animals, and in the operations which are carried on within these beings, the same wise purposes of mutual relation and dependence are observable. Thus whether we contemplate the repeated employment of the same materials, or the various important ends in many instances accomplished by the same process, we discover throughout, the utmost abridgment of labour, so that the greatest possible effect is everywhere produced by the simplest possible means.

Secondly. The general subserviency of the mechanical arrangements of the frame of organized beings, to the chemical operations that are carried on within them, is of still greater interest and importance, even than the mechanical arrangements of the frame have been shown to be. We may view an organized being as a piece of intricate machinery, adapted to the physical and the chemical properties of matter. The adaptation of this machinery to the physical properties of matter, belongs to another department. Our attention is directed solely to the chemical adaptations. The performance of the chemical changes within organized beings through the interposition of mechanical arrangements, as has been stated in a former part of this work, establishes beyond a doubt that these chemical changes have a real existence. Thus when we witness such a display of elaborate arrangements as are exhibited in the mechanism of the digestive organs and of the circulating system, the purpose of which arrangements is merely to produce a few chemical changes in the food and in the blood, it is evident that the chemical changes so produced must be at least as real, as the mechanical structure by means of which they are effected.

The adaptations of mechanical arrangements in the structure of organized beings, to the pre-existing chemical properties of matter, afford also an evidence of design, not less impressive than unequivocal. The most determined sceptic cannot assert that there is any necessary relation, or indeed any relation whatever between the mechanical arrangements, and the chemical properties to which they administer. There is no reason why the chemical changes of organization

should result from the mechanical arrangements by which they are accomplished; neither is there the slightest reason why the mechanical arrangements in the formation of organized beings, should lead to the chemical changes of which they are the instruments. From what cause then arose the association of the chemical changes with the mechanical arrangements? How were the chemical operations of digestion and of respiration brought into union with the mechanical apparatus of digestion, and with the circulating system? The co-existence of things so entirely dissimilar and having no kind of mutual relation, can be explained only on the supposition that a will exists somewhere, and also a power to execute that will. The existence is thus unavoidably acknowledged of a Being, who knowing every pre-existing chemical property of matter and willing to direct these chemical properties to a specific object, has contrived for that purpose an apparatus admirably fitted to attain His object. Such is the explanation—the only possible explanation of the subserviency of mechanism to chemistry in the processes of organic life. And what is this explanation but our argument of design, in terms that seem absolutely irresistible?

Thirdly. The perpetual renovation and decay to which all organized beings are liable, may be considered as a part only of the great round of changes we witness in every thing that has been created. The world itself as we have seen, appears to have been at intervals subjected to changes involving even the fundamental laws by which it is governed. Nothing therefore belonging to the world, can reasonably be expected to be permanent. Had there been even an approach to such permanence, the beautiful adaptations of organized beings to the pre-established laws of inanimate matter, and all the other wonderful arrangements we have described, could not have been manifested as they now are. Besides, to the changes we ourselves undergo, we are indebted for the greater part of the enjoyments of our life. If none died, none could be born; and the present order of human society could have no existence. There would be none of the pleasing relations of parent and offspring; none of the agreeable variety of childhood, of youth, of maturity, and of age, experienced by every individual; which with all

the other numerous relations of society, incidental to the persons of different individuals, contribute so largely to human happiness. Were man exempt from change, whether the rest of the world were supposed to be progressive as it is, or to be stationary as regards him, the same uniform and dull monotony would prevail, the same want of motive. In short with our present constitution and feelings, perpetuity and uniformity are physically and morally impossible.

But why it has a thousand times been asked, why has the world been so constituted? Why this unceasing round of change? Whence its origin? What its object?—Such questions the Great Author of the Universe alone can answer. But as within those narrow limits by which our observations are bounded, wherever we can trace His designs we see that His works are never without an object, we cannot doubt that in determining their perpetual renovation and decay there is no less an object, though the object be above our comprehension. By placing immaterial and intelligent beings for a time in personal connexion with matter, He has indeed communicated to them a knowledge of those properties of matter which so strikingly display His wisdom and power; and this as we have stated may have been one of His objects, but to speculate further on points so utterly beyond our capacity, would be presumptuous; for who can "know the mind of God, or who hath been His counsellor?"

We have thus given a brief outline of what has been denominated the Chemistry of organization; in other words, an account of those changes and combinations which, through the operation and the agencies of inorganic matter, organic agents are capable of effecting. The information it has been in our power to give, though imperfect, we have shown to be amply sufficient not only to demonstrate the astonishing wisdom and foresight, with which organized beings in as far as we can understand them have been contrived and formed, but the infinitely higher perfection of both these attributes requisite to impart to organization that vitality, the nature of which so entirely surpasses our conception.

We shall now finally close this volume with a few con-

siderations on the future progress of Chemistry, on the means by which this science may be applied to physiological research, and on the tendency of physical knowledge in general.

Chemistry as we pointed out in the introduction of this treatise, forms the connecting link between that kind of knowledge which is founded on quantity, and those kinds of knowledge which rest solely on experience. All our experimental knowledge that is not chemical, for instance all physiology relative to the phenomena of life, is wholly removed from the logic of quantity, and depends entirely on observation. Now so far as the logic of quantity is applicable, so far are we certain of our conclusions: as certain at least as we are of our own existence, or that we see and hear. But when this logic cannot be applied, our conclusions are no longer such as must be—no longer follow from our premises as a necessary consequence, but are only for the most part such as may be; that is to say, have no more than that degree of probability which arises from the evidence we have of the truth of the phenomena or events forming our premises.

In all knowledge depending on mere observation or experiment, what we know is grounded on our own observation and experience, or on the observation and experience of others. What we ourselves observe, we too often observe very imperfectly, or do not understand when observed. But phenomena or events, the knowledge of which we are obliged to receive at second hand, on the testimony of others, and which may have been observed through the distorted medium of ignorance or of prejudice—may even have been wilfully misrepresented—of these phenomena we have a still less assurance. If a phenomenon or event has happened only once, and be therefore historical, we are under the necessity of acquiescing in its truth or of estimating its probability, according to the rules of evidence. If the phenomenon or event be of frequent occurrence, or if it be capable of being brought under our own observation, in order to remove our uncertainty we endeavour to observe it ourselves, in short we make an experiment. Such is the method we pursue in obtaining all that knowledge which is the result of mere observation. The different events succeed one another, but

we know not wherefore; we see not their mutual connexion. We believe that an event will probably follow another event, because the one event has always followed the other, or because of some other probability; but we cannot discover that necessary connexion between the two events, which so irresistibly leads us to determinate conclusions where we can apply the laws of quantity.

The foregoing statements may be viewed as a continuation of those which were offered as preliminary to the first treatise in this volume; and relate chiefly to the progress of chemistry. Chemistry being a science of observation, we can form but a very imperfect conception of its future progress; because we cannot by reasoning, anticipate the discovery of those chemical facts which are yet concealed. The progress chemistry has made within these few years is truly astonishing; and when a more rigorous mode of observation shall be adopted—in short when chemistry shall be brought more under the control of the laws of quantity—a control which will be exercised, at least indirectly—it is impossible to foretell the degree of perfection chemistry may attain as a science. But for many years yet to come, the progress of chemistry must depend solely on experiment; and its cultivators must be satisfied with the comparatively humble office of discovering the actual chemical changes which bodies effect on each other.

Since then in knowledge derived from observation, an acquaintance with what exists and with what is done is indispensable; to obtain a clear accurate and unequivocal conception of natural objects and of the changes to which they are liable, is the first duty of every observer and of every experimentalist. Nor is there any observer or experimentalist however unpretending, who may not add to the stock of ascertained facts, so varied and inexhaustible are the stores of nature. Another duty of every one who engages in observation or experiment, is to become the faithful historian of what he witnesses; to narrate in plain and intelligible language, the event or phenomenon he has observed, so that a just notion of it may be conveyed to others. We say a just notion; in the greater number of instances a perfect notion is impossible, because what is seen cannot be expressed by language. But to give a just

notion, that is a notion which though incomplete, has no foreign or false gloss, is within the power of every observer; and to give such a notion of the facts he narrates, ought to be his chief study. One testimony of so faithful a witness is often invaluable, and worth a thousand vague and inaccurate observations, which are only calculated to bewilder or to mislead, and thus are worse than useless.

The next rule which an interpreter of nature ought to bear in mind, is not to attempt too much at first; but in order to establish a sure foundation for his succeeding labours, be content with obvious and unexceptionable facts, and so arrange these facts that they may lead to others. To elicit novel and prominent facts is the lot of few, and any one may happen to be so successful. But all as before stated may investigate truth, and thus contribute more or less toward the advancement of knowledge. Moreover the humblest contributors may rest assured that they are imperceptibly raising a structure, which will sooner or later include the conspicuous labours of their more fortunate coadjutors; in which structure these labours will indeed still appear conspicuous, though their importance will be diminished as the fabric is extended around them.

The remarks just now made, have special reference to the application of chemistry to physiology. The cautious and judicious application of chemistry to physiology has already effected much, and is capable of effecting still more. Indeed no one can pretend to be a physiologist who is ignorant of chemistry. But chemistry in its present state, in order to be made really useful, must be applied in a manner the most guarded and sparing—must indeed be rigidly confined to the ascertainment of what the living principle does, and how the living principle operates on the constituent elements of matter. With the living, the animative properties of organized bodies, chemistry has not the smallest alliance; and probably will never in any degree elucidate these properties. The phenomena of life are not even remotely analogous to anything we know in chemistry, as exhibited among inorganic agents. The great error of chemists therefore, has been their attempting to apply that science to explain phenomena, for the explanation of which, chemistry as we have said is totally valueless. Such perversion of the

reasoning powers has too much prevailed among physiologists in all ages. In the earlier ages, heat was considered the principle of life. In later times, electricity has been discovered; and to electricity, the same functions have been ascribed. Life according to other philosophers, is motion. But the progress of science has dispelled all these illusions; the origin of the obscure and evanescent principle of life must be sought elsewhere. By heat, many wonderful things may be accomplished; but heat will not act of itself. The powers of electricity are still more wonderful than the powers of heat; but electricity we know to be governed in its mode of action by certain laws; and we know that electricity gives no sign of intelligence. In the same manner, life as we are acquainted with it, cannot exist without motion; but motion can exist without life. Life and motion consequently are not synonymous terms; nor can we conceive the existence of motion without a mover. In short the living principle as we have already shown, is something different from and superadded to the common agencies of matter; over which to a certain extent it has a control. Thus the phenomena exhibited by the mysterious agency of life are strictly comparable only with one another, and have no relation to any inorganic phenomena.

But the desire of the physiologist to ascribe to the agencies of inorganic matter, those operations ascertained to be carried on within living bodies, is merely a display of that innate propensity of the human mind, by which we are led to seek after First Causes. The conceptions of the physiologist regarding the principle of life are the same therefore, as the conceptions of mankind in all ages regarding the Great First Cause—the Deity himself. The poor untutored savage "sees God in every cloud, and hears him in the wind." The complacent philosopher smiles at the credulity of the savage, and perhaps deifies "the laws of nature!" Both are alike ignorant; nor is the imagined Supreme Being of the untaught savage in any degree more absurd than the imagined Pantheism of the philosopher. The winds we know can be referred to other causes to which they are immediately owing; so with the progress of knowledge, the "laws of nature" have been found to merge and will continue to be found to merge into other laws still more gene-

ral; still proving that these "laws of nature" are all alike, mere delegated agencies. Hence the tendency of knowledge and of its due application, is to abstract the attention from inferior things, and to fix the mind on the source of all knowledge and of all power—the GREAT FIRST CAUSE; who exists and acts throughout the universe; whom we can approach only by studying His works; and whose works, an eternity will be inadequate to explore.*

* We have permitted these observations on the application of Chemistry to Physiology to remain as in the former editions of this work; because we think attention to them is still more requisite than when they were first published. From want of due attention to the nature and powers of Chemistry, this most interesting and valuable branch of knowledge has in recent times, been sadly misapplied; and without more caution in future, we fear it will be ultimately discarded by all those who carefully study the phenomena of living beings.

APPENDIX,

CONTAINING

NOTES ILLUSTRATIVE AND SUPPLEMENTARY.

APPENDIX.

BOOK I. CHEMISTRY.

Chapter viii. *page* 63, *&c.* In this edition we have omitted the attempt to illustrate homogeneous and heterogeneous molecular arrangements. The following note is intended to supply this omission, and to furnish a key to the whole subject:

It is assumed that—

1. All matter as it is known to us, ultimately exists in the condition of molecules; which molecules we consider to be virtually spheres or spheroids.—See note, page 65.

2. All the spherical or spheroidal molecules when unimpeded, have a tendency to revolve on their axes, with velocities which in molecules having the same weight, are under similar circumstances fixed and definite; but which velocities according to a law which need not be here specified, increase in molecules of different weights, as the weights of the molecules diminish.

3. Material forces, whether exerted between masses or molecules of matter, are two only—the one force being attractive, centripetal and positive; the other repulsive, centrifugal, and resultant, *i. e.* (resulting from the motion of a mass or molecule on its axis.)

4. These two forces exerted between two masses of matter, constitute the forces of gravitation; while exerted between two molecules of matter, they constitute the forces of polarization (Polarity.)

5. The phenomena of Polarity result from the motions of two contiguous molecules on their axes. Polarity is of two kinds—Polarity resulting from the motions of two similar

molecules, Homogeneous polarity, (Cohesive attraction and divulsion); and Polarity resulting from the motions of two dissimilar molecules, Heterogeneous polarity, (Chemical attraction and repulsion).

Homogeneous polarity.

6. *a.* When two similar and contiguous molecules having their axes and poles in the parallel position represented in Fig. 6 page 60, move together, their equatorial motions being in opposite directions mutually impede each other, and allow (other circumstances being favourable) the two molecules to unite into one statical molecule, in virtue of their reciprocal attractive forces. A large number of pairs of molecules similarly posited, unite together symmetrically and form a solid mass or crystal.

7. *b.* When two similar and contiguous molecules having their axes and poles in the parallel position represented in Fig. 7 page 60, (*i. e.* reversed,) their equatorial motions being in the same direction, so far from impeding assist each other's motion, and produce a tendency to separation between the two contiguous molecules. A large number of pairs of molecules similarly posited produce the fluid or gaseous condition of bodies.

8. *c.* When two similar and contiguous molecules have such velocity that their axes assume a position at right angles to each other, their reciprocal influences are neutralized, and the two contiguous molecules have neither a tendency to unite nor to separate. A large number of pairs of molecules similarly posited, constitute the liquid condition of bodies.

From the preceding assumptions it may be inferred: first, that—two similar and contiguous molecules in motion, in the position *a*, may become relatively statical by combining at any two corresponding points between their equators and poles inclusive; and consequently that solids may result from numerous symmetrical combinations in all these intermediate points. The points of union between two contiguous molecules may be supposed to be determined by the figures and velocities of the molecules; and the character of the compound molecule may vary somewhat according

as the points of union are at the poles or at the equators. Secondly, that—two similar and contiguous molecules in motion in the position *b*, can never become statical at their poles, where their motions are in opposite directions.

Heterogeneous polarity.

Considering now the relations of two contiguous molecules having unequal weights and velocities in the three positions *a*, *b*, and *c*, it is assumed that—

9. *a.* When two dissimilar and contiguous molecules moving with different velocities have their axes and poles in the same position *a*, their opposite equatorial motions cannot arrest each other so as to allow of the statical union of the two contiguous molecules at any point between their equators and poles. But when two dissimilar and contiguous molecules moving with different velocities, have their axes in a straight line, and their dissimilar poles contiguous and of course moving in the same direction, the two dissimilar molecules may unite statically at those moments when the motions of the two molecules are coincident; *e.g.* two molecules, the one moving twice as fast as the other, may unite at every revolution of the slower molecule, which will be coincident with every second revolution of the quicker. Hence the more simple the relation between the weights and motions of two molecules, the more readily will they unite, and the more stable will be their union.

10. *b.* When two dissimilar and contiguous molecules moving with different velocities, have their reversed axes and poles in the parallel position *b*, their equatorial motions being in the same direction have a tendency to separate the two molecules; while their axial or polar motions being in opposite directions also prevent union at their poles.

11. *c.* When two dissimilar contiguous molecules have such velocity that their axes assume an angular, and more especially a rectangular position, they have neither a tendency to unite nor to separate; but such a position may be considered as very unstable, and favourable for change.

The preceding assumptions lead to the inference, that Heterogeneous or Chemical union is only a particular case of Homogeneous statical union; and that Heterogeneous

or Chemical repulsion is the same, or rather results from the same cause, as Homogeneous divulsion. The assumptions further lead to the important inference that the phenomena of Chemistry can be understood only by studying them in connexion with the phenomena of Cohesion. To enter on the subject in detail would occupy a volume. We can only say that those who will take the pains to study molecular phenomena in general, and particularly Chemistry on these principles, will obtain an insight into many matters at present inexplicable.

It remains to conclude with one or two remarks on imponderable molecular operations:

12. The molecules of the imponderable matters light and heat are assumed to be immeasurably smaller, and to move with inconceivably greater velocity, than the molecules of any ponderable substance; their substance is supposed to be of such a nature as to allow them, or at least their influences, to become virtually more or less oblate in proportion to the intensity of their motion; *per se* probably also the imponderable matters light and heat are insensible to us.

13. We suppose that the molecules of imponderable matters, from their extreme minuteness are capable of pervading and operating within and among ponderable molecules; that the intensity of the motion of the molecules of imponderable matters influences the motions of the molecules of ponderable bodies, and urges the ponderable molecules to move with velocities far beyond the velocities proper to them; that ponderable molecules in this unnatural state of velocity are the cause of the sensations we term light, heat, &c.; and that the molecules of imponderable matters thus appear in the character of agents.

14. Finally, we assume that polarity becomes sensible in fluids when molecules are more or less separated from the neutralizing influence of their contiguous molecules, and move together in the same direction; that the opposite motions of contiguous molecules thus separated and moving together alone, are the cause of opposite (positive and negative) polarities; that the intensity of the polarities of molecules is of two kinds, the intensity depending on the greater or less velocity of the molecules; and the intensity depend-

ing on the greater or less separation of the poles of contiguous molecules; and finally, that the quantity of polarity is proportional to the number of pairs of molecules moving together at the same time and in the same direction.

Page 44.—Light and heat, and indeed all fluids besides, have been stated to possess two kinds of repulsive power: that repulsive power which is common to them as fluids, and which may be imagined to result from the aggregate motions of all the molecules of which they are composed; and that self-repulsive power which we have supposed to depend on the mutual action of the contiguous or alternate molecules of fluids, when these molecules are in the relative positions which they are naturally inclined to assume, particularly in a state of motion. It is probable, however, that the marshalling of the individual molecules, as those of light, does not become apparent till they approach or pass through some ponderable and transparent medium; and the passage of light and heat through such a medium may perhaps be rendered more intelligible by the following exposition of what appears to happen with respect to gaseous bodies.

The force of diffusion, on which depends the rapidity of the motion of gaseous bodies through any permeable medium, increases as their specific gravity diminishes. Thus the force with which the lightest of these bodies, hydrogen, struggles to escape through any porous matter, is almost incredible; according to Mr. Graham's experiments, sufficient to raise a column of water from twenty to thirty inches. This rapidity of motion seems only explicable on the supposition that the individual molecules of the gas, in their passage through narrow canals are guarded from external and lateral influence; and are thus enabled to assume those positions which are natural to them, and in which their mutual self-repulsion is the greatest possible. Hence a single row of self-repulsive molecules of a gas (or other self-repulsive fluid) passing through the minute aperture of a porous vessel into a vacuum, or what is analogous, into another gas having different self-repulsive powers, may be compared to a row of bullets urged by an electric fluid in quick succession through a gun-barrel; but with this

difference, that the gaseous molecules propel each other, instead of being like the bullets propelled by a foreign agency. The explanation now offered of the passage of the molecules of a gas through a narrow canal or through any porous matter, may as we have said be applied not only to the passage of light and heat through various media, but also to the passage of liquids through various bodies, by the processes which have been termed endosmose and exosmose. Do these forces operate in capillary attraction? Are the molecular motions of fluids the cause of those motions which solid particles of matter diffused through them sometimes exhibit?

Page 75.—Diffusion of gaseous bodies. There are three distinct modifications or cases of gaseous diffusion, of which the following brief statement will afford some explanation.

First. The diffusion through each other of two different gaseous bodies of the same or of different specific gravities.

Secondly. The diffusion through each other of a gaseous body and a vapour.

Thirdly. The diffusion through each other of two portions of the same gaseous body or vapour, having different temperatures and consequently different specific gravities.

First. Of these three modifications or cases of gaseous diffusion, the diffusion of two different gaseous bodies through each other is the best known, and is we believe the only case of diffusion that has been experimentally investigated. By way of illustrating the phenomena, let us suppose a flexible air-tight bag to be furnished with a stop-cock, and to be filled with a gaseous body, having under the same temperature and pressure precisely the same specific gravity as atmospheric air. Let us now suppose the stop-cock to be opened. Immediately, the gaseous body in the bag and the external atmospheric air will begin to intermingle with equal velocities; so that for each molecule of the gaseous body passing outwards, a molecule of atmospheric will pass inwards; and consequently under every circumstance of admixture, the bulk of gaseous matter existing in the bag will be the same. This is the simplest case of the diffusion of gaseous bodies throughout each other, and will serve to give the reader some notion of that most remarkable pheno-

menon in its elementary form. Philosophers as we have said, explain the phenomena of diffusion by supposing that the molecules of any gas are self-repulsive or repel each other, in preference to the molecules of all other gases; so that each gas is as it were a vacuum to the other; and the mode in which this self-repulsive power may be imagined to operate, has been stated in the preceding note.

The case to be next considered is that in which the air-tight bag is supposed to contain some gaseous body, having a specific gravity different from atmospheric air, as for instance hydrogen gas. In this case, on opening the stop-cock, the hydrogen in the bag and the exterior atmospheric air will begin to commingle with a force and velocity proportional to the quantities of the gases diffused, which quantities will be found to vary inversely as the square roots of the specific gravities of hydrogen gas and atmospheric air; that is to say, the volume of atmospheric air diffused inwards being supposed to be equal to 1, the volume of hydrogen diffused outwards will be equal to 3·8 nearly. These phenomena show that the velocity or rate of diffusion of gaseous bodies through each other, has reference to their specific gravities.

Secondly. The law of diffusion of a gaseous body and a vapour through each other, is probably different from the law of the diffusion of two gaseous bodies through each other; because the self-repulsive properties of molecules of vapours and of gases are probably different. On the supposition that the velocities of diffusion between a gaseous body and a vapour have reference to the specific gravities of the gaseous bodies, the velocity of diffusion of a vapour, (the vapour of water for instance,) through air, must increase as the temperature diminishes, that is to say, as the specific gravity of the vapour diminishes. Hence in high latitudes the velocity of diffusion must be extreme; and this extreme velocity may be supposed to cause the total quantity of water evaporated in a given time in such latitudes to be considerable, and thus to compensate amply for the small quantity held in solution.

Thirdly. The diffusion through each other of two portions of the same gaseous body or vapour having different temperatures and consequently different specific gravities, like

the diffusion of a gaseous body and a vapour, has not we believe been the subject of experiment. But on the supposition that the self-repulsive properties of the molecules of a gas or vapour at different temperatures are different, and that the velocities of diffusion between two such portions of gaseous bodies or vapours have reference to their specific gravities, we may imagine that there is a constant tendency to diffusion between portions of air of different temperatures; as for instance between the warmer and lighter air of the equator and the colder and heavier air of the poles, between the colder and lighter vapour of the poles and the warmer and heavier vapour of the equator, or between the colder and lighter vapour of the upper regions of the atmosphere and the warmer and heavier vapour at the surface of the earth. Nor is it improbable that many natural phenomena which appear to us at present inexplicable depend on these tendencies. The diffusive powers of elastic fluids are at present very little understood or appreciated; they constitute however one of the most interesting and important subjects in physics, and would amply repay whoever would take the trouble to investigate them.

Table

Page 161.—TABLE OF TEMPERATURES. (from

Isothermal Zones.	Names of Places.	Position.					Mean Temperature of the Year.
		Longitude North.		Longitude.		Height in Feet.	
Isothermal Zones from 32° to 41°.	Nain	57°	8′	61°	20′ W	0	26·42°
	*Enontekies	68	30	20	47 E	1356	26·96
	Hospiee de St. Gothard	46	30	8	23 E	6390	30·38
	North Cape	71	0	25	50 E	0	32·00
	*Uleo	65	3	25	26 E	0	35·08
	*Umeo	63	50	20	16 E	0	33·26
	*St. Petersburg ..	59	56	30	19 E	0	38·84
	Drontheim	63	24	10	22 E	0	39·92
	Moseow	55	45	37	32 E	970	40·10
	Abo	60	27	22	18 E	0	40·28
Isothermal Zones from 41° to 50°.	*Upsal	59	51	17	38 E	0	42·08
	*Stoekholm	59	20	18	3 E	0	42·26
	Quebee	46	47	71	10 W	0	41·74
	Christiana	59	55	10	48 E	0	42·80
	*Convent of Peyssenburg	47	47	10	34 E	3066	42·98
	*Copenhagen.. ..	55	41	12	35 E	0	45·68
	*Kendal	54	17	2	46 W	0	46·22
	Malouine Islands	51	25	59	59 W	0	46·94
	*Prague..	50	5	14	24 E	0	49·46
	Gottingen	51	32	9	53 E	456	46·94
	*Zurich	47	22	8	32 E	1350	47·84
	*Edinburgh	55	57	3	10 W	0	47·84
	Warsaw	52	14	21	2 E	0	48·56
	*Coire	46	50	9	30 E	1876	48·92
	Dublin..	53	21	6	19 W	0	49·10
	Berne	46	5	7	26 E	1650	49·28
	*Geneva..	46	12	6	8 E	1080	49·28
	*Manheim	49	29	8	28 E	432	50·18
	Vienna	48	12	16	22 E	420	50·54

(*) At the Places thus distinguished, the Temperatures

METEOROLOGY.

I.

THE ENCYCLOPÆDIA METROPOLITANA.—ARTICLE—METEOROLOGY.)

Distribution of Heat in the different Seasons.				Maximum and Minimum.	
Mean Temp. of Winter.	Mean Temp. of Spring.	Mean Temp. of Summer.	Mean Temp. of Autumn.	Mean Temp. of Warmest Month.	Mean Temp. of Coldest Month.
− 0·60°	23·90°	48·38°	33·44°	51·80°	−11·28°
+ 0·68	24·98	54·86	27·42	59·54	− 0·58
18·32	26·42	44·96	31·82	46·22	+15·08
23·72	29·66	43·34	32·08	46·58	22·10
11·84	27·14	57·74	35·96	61·52	7·70
12·92	33·80	54·86	33·44	62·60	11·48
17·06	38·12	62·06	38·66	65·66	8·60
23·72	35·24	61·24	40·10	64·94	19·58
10·78	44·06	67·10	38·30	70·52	6·08
20·84	38·30	61·88	40·64	—	—
24·98	39·38	60·26	42·80	62·42	22·46
25·52	38·30	61·88	43·16	64·04	22·82
14·18	38·84	68·00	46·04	73·40	13·81
28·78	39·02	62·60	41·18	56·74	28·41
22·58	42·08	58·46	42·98	59·36	30·20
30·74	41·18	62·60	48·38	65·66	27·14
30·86	45·14	56·84	46·22	58·10	34·88
39·56	46·58	53·06	48·46	55·76	37·40
31·46	47·66	68·90	50·18	—	—
30·38	44·24	64·76	48·74	66·38	29·66
29·66	48·20	64·04	48·92	65·66	26·78
38·66	46·40	58·28	48·56	59·36	38·30
28·76	47·48	69·08	49·46	70·34	27·14
32·36	50·00	63·32	50·36	64·58	29·48
39·20	47·30	59·54	50·00	61·16	35·42
32·00	48·92	66·56	49·82	67·28	30·56
34·70	47·66	64·94	50·00	66·56	34·16
38·80	49·64	67·10	49·82	68·72	33·44
32·72	51·26	69·26	50·54	70·52	26·60

given are the results of at least 8000 observations.

TABLE OF

Isothermal Zones.	Names of Places.	Position. Latitude.		Longitude.			Height in Feet.	Mean Temperature of the Year.
Isothermal Zones from 50° to 59°.	*Clermont	45°	46′	3°	5′	E	1260	50·00°
	*Buda	47	29	19	1	E	494	51·08
	Cambridge (U.S.)	42	25	71	3	W	0	50·36
	*Paris	48	50	2	20	E	222	51·08
	*London	51	30	0	5	W	0	50·36
	Dunkirk	51	2	2	22	E	0	50·54
	Amsterdam	52	22	4	50	E	0	51·62
	Brussels	50	50	4	22	E	0	51·80
	*Franeker	52	36	6	22	E	0	51·80
	Philadelphia ..	39	56	75	16	W	0	53·42
	New York	40	40	73	58	W	0	53·78
	*Cincinnati	39	6	82	40	W	510	53·78
	St. Malo	48	39	2	1	W	0	54·14
	Nantes..	47	13	1	32	W	0	54·68
	Pekin	39	54	116	27	E	0	54·86
	*Milan	45	28	9	11	E	390	55·76
	Bordeaux	44	50	0	34	W	0	56·48
Isothermal Zones from 59° to 68°.	Marseilles	43	17	5	22	E	0	59·00
	Montpellier.. ..	43	36	3	52	E	0	59·36
	*Rome	41	53	12	27	E	0	60·44
	Toulon..	43	7	5	50	E	0	62·06
	Nangasacki	32	45	129	55	E	0	60·80
	*Natchez	31	28	90	30	W	180	64·76
Isothermal Zones from 68° to 77°.	*Funchal	32	37	16	56	W	0	68·54
	Algiers..	36	48	3	1	E	0	69·98
Isothermal Zones above 77°.	*Cairo	30	2	31	18	E	0	72·32
	*Vera Cruz	19	11	96	1	W	0	77·72
	*Havannah	23	10	82	13	W	0	78·08
	*Cumana	10	27	65	15	W	0	81·86

(*) At the Places thus distinguished, the Temperatures

TEMPERATURES.

Distribution of Heat in Different Seasons.				Maximum and Minimum.	
Mean Temp. of Winter.	Mean Temp. of Spring.	Mean Temp. of Summer.	Mean Temp. of Autumn.	Mean Temp. of Warmest Month.	Mean Temp. of Coldest Month.
34·52°	50·54°	64·40°	51·26°	66·20°	28·04°
33·98	51·08	70·52	52·34	71·60	27·78
33·98	47·66	70·70	49·82	72·86	29·84
38·66	49·28	64·58	51·44	65·30	36·14
39·56	48·56	63·14	50·18	64·40	37·76
38·48	48·56	64·04	50·90	64·76	37·75
36·86	51·62	65·84	51·62	66·92	35·42
36·68	53·24	66·20	51·08	67·28	35·60
36·68	51·08	67·28	54·32	69·08	32·90
32·18	51·44	73·94	56·48	77·00	32·72
29·84	51·26	79·16	54·50	80·78	25·34
32·90	54·14	72·86	54·86	74·30	30·20
42·26	52·16	66·02	55·76	66·92	41·74
40·46	54·50	68·54	55·58	70·52	39·02
26·42	56·30	82·58	54·32	84·38	24·62
36·32	56·12	73·04	56·84	74·66	36·14
42·08	56·48	70·88	56·30	73·04	41·00
45·50	57·56	72·50	60·08	74·66	44·42
44·06	56·66	75·74	60·98	78·08	42·08
45·86	57·74	75·20	62·78	77·00	42·26
48·38	60·80	75·02	64·40	77·00	46·40
39·38	57·56	82·94	64·22	86·90	37·40
48·56	65·48	79·16	66·02	79·70	46·94
64·40	65·84	72·50	72·32	75·56	64·04
61·52	65·66	80·24	72·50	82·76	60·08
58·46	73·58	85·10	71·42	85·22	56·12
71·96	77·90	81·50	78·62	81·86	71·06
71·24	78·98	83·30	78·98	83·84	69·98
80·24	83·66	82·04	80·24	84·38	79·16

given are the result of at least 8000 observations.

Page 158.—Explanation of the Maps.

The accompanying Map on which are traced the different isothermal lines, has been compiled from the researches of Professor Dove, which are more recent than those of Humboldt; hence the results will be found to differ somewhat from those of the latter philosopher, which were used in former Editions of this work. The general character of these isothermal lines is, that in Europe they are convex and in Asia and America concave towards the Pole, and that they gradually become less and less convex and concave, as they approach the Equator.

The sketches on the next page are intended to show the height of the snow-line and the effect of elevation on the growth of plants in various latitudes, and the geographical distribution of the principal animals and plants useful to man. An attempt has been made at the same time to illustrate the diminution of heat and light in receding from the Equator to the Poles.

The reader interested in Meteorological pursuits is referred to "*A complete Course of Meteorology*," by Professor L. F. Kaemtz; recently translated into English, and published by H. Bailliere.

Page 211.—*Of the effects of foreign bodies in the atmosphere.*—Many years ago, particular circumstances led us to form the opinion that a combination of water and oxygen is a frequent if not a constant ingredient in the atmosphere. This ingredient which we suppose to be a vapour, and analogous to (we do not say identical with) the deutoxide of hydrogen, may be imagined to act as a foreign body and thus to be the cause of numerous atmospheric phenomena which at present are very little understood. Among such phenomena are those of evaporation considered in the text.

When treating of the composition of atmospheric air, we observed that the best analyses almost invariably indicated a slight excess of oxygen above the amount of 20 per cent. which there ought to be in the atmosphere if its composition were as there can be little doubt that it is, determined by the laws of chemical proportion. Now this excess of oxygen in the atmosphere we have every reason to think, becomes periodically associated in some way with the vapour which is also in the atmosphere; and thus not only modifies the properties of the vapour, but at the same time materially influences the rate of evaporation from the earth's surface. This excess of oxygen may operate in the following manner. The vapour in union with oxygen (deutoxide of hydrogen ?) ceases of course to act as vapour; hence in air saturated with vapour and as moist as possible, if a portion of the vapour were suddenly to combine with oxygen the air would as suddenly appear to become dry, though in reality it contained the same quantity of water in solution as before. Moreover the rate of evaporation would be increased by such a combination of vapour and oxygen, for its effects whatever these might be would be superadded to the ordinary effects of atmospheric air in producing evaporation, and would thus more or less increase the quantity of water converted into vapour.

Oxygen in this state of combination with vapour seems to be particularly grateful, if not necessary to animal life. The air in which oxygen abounds so combined is dry, bracing, and exhilarating; while its sudden abstraction and the predominance of moisture, induces the opposite feeling of dullness and listlessness. It is probable that some soils and situations are more favourable than others to the combina-

tion of oxygen with vapour, and that places are more or less healthy according as this combination of oxygen is present or absent.

The oxygen and vapour in this combination are so feebly associated, that they appear to be separated by the slightest cause. Hence the results of every common analysis and examination of air, are the same nearly as if such a state of combination did not exist. We may mention however as corroborative of our opinion, the bleaching qualities of dew and of the air itself; as also the large proportion of oxygen sometimes contained in snow water and in rain water; attention being at the same time directed to the well-known bleaching qualities of the deutoxide of hydrogen.

Much more might be said on this enrions snbject, especially regarding its relation to the eleetricity of the atmosphere. But we desist for the present, as the difficulties attending an investigation of the atmosphere, and, more than all, the total want of opportunity, have rendered us unable satisfactorily to verify the opinion we have advanced, which opinion therefore is to be understood as conjectural only, and as stated with the view of drawing the attention of those more fortunately situated to so important an inquiry.

[The body here alluded to appears to be the "zone" of Schönbein, about the nature and eomposition of which so much has been written. The most recent experiments are in favour of its consisting of an allotropic condition of oxygen.—G.]

Page 247.—The table follows, illustrating the distribution of plants over the globe, to which we have referred in the text. It has been copied immediately from Lindley's Introduction to Botany.

Groups.	Proportion to the whole mass of Phænogamous Plants.		
	Equatorial Zone, Lat. 0°—10°.	Temperate Zone, Lat. 45°—52°.	Frozen Zone, Lat. 67°—70°.
Agamæ (*Ferns, Lichens, Mosses, Fungi*)	Plains ... ... $\frac{1}{15}$ Mountains ... ... $\frac{1}{5}$	... $\frac{1}{2}$ ...	... $\frac{1}{1}$
Ferns alone	Countries nearly flat .... $\frac{1}{20}$ Countries very mountainous $\frac{1}{3}$ to $\frac{1}{8}$	... $\frac{1}{70}$ ...	... $\frac{1}{25}$
Monocotyledones	Old Continent ... ... $\frac{1}{5}$ New Continent ... ... $\frac{1}{6}$	... $\frac{1}{4}$ ...	... $\frac{1}{3}$
Glumaceæ (*Junceæ, Cyperaceæ, Gramineæ*)	... ... $\frac{1}{11}$ ...	... $\frac{1}{8}$ ...	... $\frac{1}{4}$
Junceæ alone	... ... $\frac{1}{400}$ ...	... $\frac{1}{90}$ ...	... $\frac{1}{25}$
Cyperaceæ alone...	Old Continent ... ... $\frac{1}{22}$ New Continent ... ... $\frac{1}{50}$	... $\frac{1}{20}$ ...	... $\frac{1}{9}$
Gramineæ alone	... ... $\frac{1}{14}$ ...	... $\frac{1}{12}$ ...	... $\frac{1}{10}$
Compositæ	Old Continent ... ... $\frac{1}{18}$ New Continent ... ... $\frac{1}{12}$	Old Continent $\frac{1}{8}$ New Continent $\frac{1}{6}$	... $\frac{1}{13}$
Leguminosæ	... ... $\frac{1}{10}$ ...	... $\frac{1}{18}$ ...	... $\frac{1}{35}$
Rubiaceæ...	Old Continent ... ... $\frac{1}{14}$ New Continent ... ... $\frac{1}{25}$	... $\frac{1}{60}$ ...	... $\frac{1}{80}$
Euphorbiaceæ	... ... $\frac{1}{32}$ ...	... $\frac{1}{80}$ ...	... $\frac{1}{500}$
Labiatæ	... ... $\frac{1}{40}$ ...	America ... $\frac{1}{40}$ Europe ... $\frac{1}{25}$	... $\frac{1}{70}$
Malvaceæ...	... ... $\frac{1}{35}$ ...	... ... $\frac{1}{200}$	... $\frac{0}{0}$
Ericeæ	... ... $\frac{1}{130}$ ...	Europe ... $\frac{1}{100}$ America ... $\frac{1}{36}$	... $\frac{1}{25}$
Amentaceæ	... ... $\frac{1}{800}$ ...	Europe ... $\frac{1}{45}$ America ... $\frac{1}{25}$	... $\frac{1}{20}$
Umbelliferæ	... ... $\frac{1}{500}$ ...	... ... $\frac{1}{40}$	... $\frac{1}{60}$
Cruciferæ...	... ... $\frac{1}{800}$ ...	Europe ... $\frac{1}{18}$ America ... $\frac{1}{60}$	... $\frac{1}{24}$

BOOK III.

CHEMISTRY OF ORGANIZATION.

Page 276.—Table III.—The numbers given in this table are not to be understood as representing the exact composition of the different substances. The numbers therein specified are given principally to illustrate homogeneous forces as we suppose them to influence the composition of bodies. Similar notice was drawn to the influence of homogeneous forces when treating of the composition of oxalic acid, page 104.

Page 361.—It may be proper to state that recent observers have not been able to detect distinct apertures opening from the lacteals into the intestines.

[This statement is too dubious. The terminations of the lacteals are invested with a layer of epithelium, through the medium of which absorption is effected; but the exact method by which this result takes place is not agreed upon; there is no doubt, however, that the lacteals have not open mouths.—G.]

Page 285.—The albuminous or some nearly allied principle here alluded to, is that which we suppose to be converted into gelatine during the respiratory processes; or in certain forms of disease into sugar, the azote never having been associated; or having been associated, afterwards separated.

TABLE III.

Vegetable Proximate Elements; *Crystallizable.*

Prox. Element.	Carbon.	Hydrog.	Azote.	Oxygen.	Water.
Cane sugar ..	144	22		176	198
Grape sugar c.	144	28		224	252
Milk sugar c.	144	24		192	216
Acetic acid ..	$\frac{144}{6}$	$\frac{18}{6}$		$\frac{144}{6}$	$\frac{162}{6}$
Lactic acid ..	$\frac{144}{4}$	$\frac{20}{4}$		$\frac{160}{4}$	$\frac{180}{4}$

Animal Proximate Elements; *Crystallizable.*

Prox. Element.	Carbon per cent.	Hydrog. per cent.	Azote per cent.	Oxygen per cent.	

Vegetable Proximate Elements; *not Crystallizable.*

Prox. Element.	Carbon.	Hydrog.	Azote.	Oxygen.	Phosphates per cent.	Water.
Starch ..	144	20		160	23	180
Gum	144	22		176	?	198
Lignin ..	144	20		160	?	180

Animal Proximate Elements; *not Crystallizable.*

Prox. Element.	Carbon per cent.	Hydrog. per cent.	Azote per cent.	Oxygen per cent.	Phosphates per cent.	Sulfur per cent.
Albumen ..	54·84	7·09	15·83	21·23	·33	·68
Fibrin ..	54·56	6·90	15·72	22·13	·33	·36
Cascin ..	54·96	7·15	15·80	21·73		·36
Gelatine ..	50·05	6·47	18·35	25·13	?	?

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